656

A/134

SCIENCE ON THE MARCH

UNIT EIGHT

ELECTRIC CURRENTS

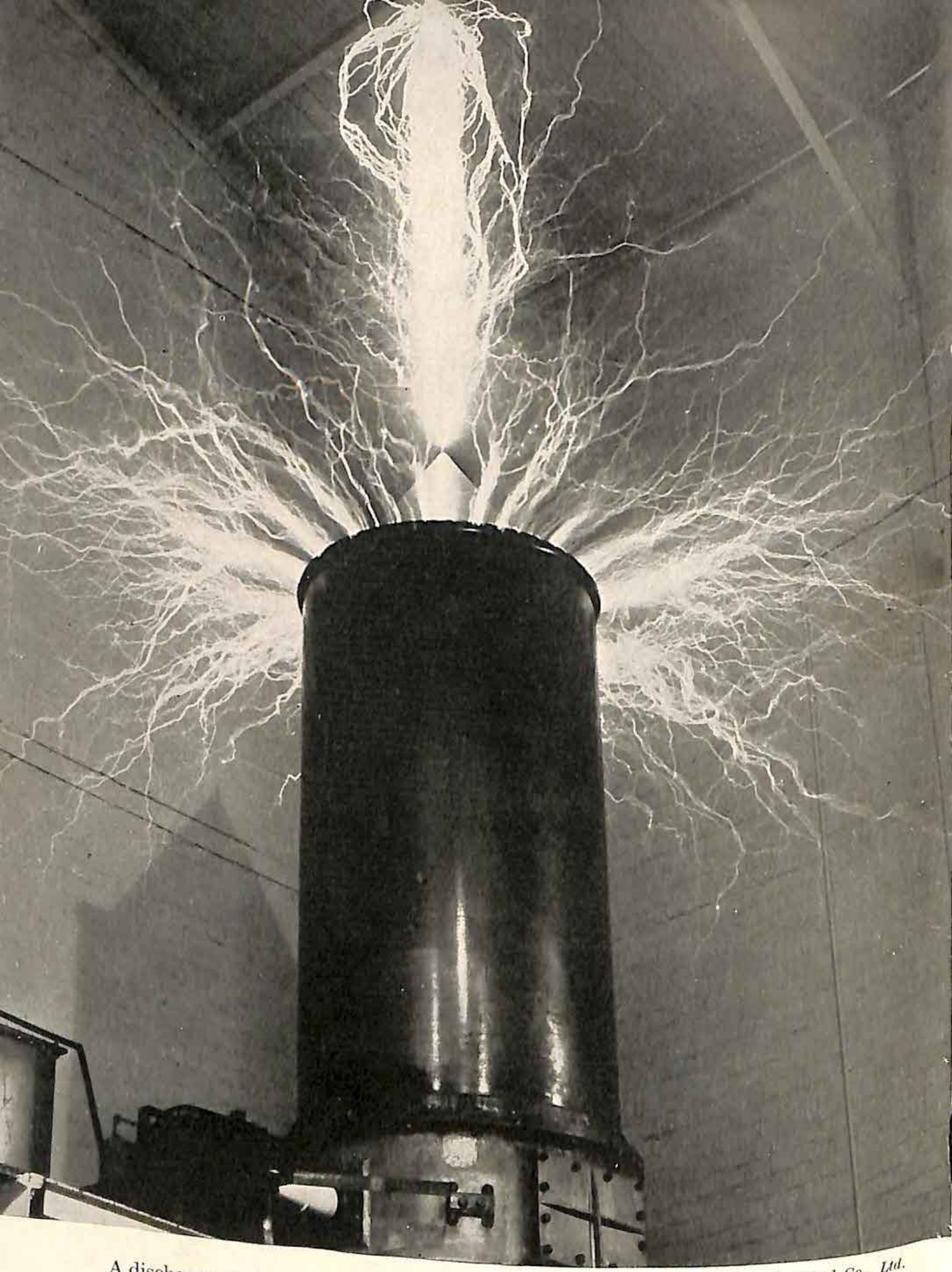
658
3732

SCIENCE ON THE MARCH

UNIT EIGHT

ELECTRIC CURRENTS

A/137
STATE INSTITUTE OF EDUCATION
BANIPUR



Courtesy, Metropolitan-Vickers Electrical Co., Ltd.

A discharge of electricity at 750,000 volts. Can you estimate its length by comparing it with the size of the bricks on the wall ?

SCIENCE ON THE MARCH

UNIT EIGHT

ELECTRIC CURRENTS

Philip E. Heafford

General Editor: **Charles H. Dobinson**

STATE INSTITUTE OF EDUCATION

Library
Calcutta
Road

1724

LONGMANS

LONGMANS, GREEN AND CO LTD
48 GROSVENOR STREET, LONDON W1
RAILWAY CRESCENT, CROYDON, VICTORIA, AUSTRALIA
443 LOCKHART ROAD, HONG KONG
PRIVATE MAIL BAG 1036, IKEJA (LAGOS)
44 JALAN AMPANG, KUALA LUMPUR
ACCRA, AUCKLAND, IBADAN, KINGSTON (JAMAICA)
NAIROBI, SALISBURY (RHODESIA)
LONGMANS SOUTHERN AFRICA (PTY) LTD
THIBAULT HOUSE, THIBAULT SQUARE, CAPE TOWN
LONGMANS, GREEN AND CO INC
119 WEST 40TH STREET, NEW YORK 18
LONGMANS, GREEN AND CO
137 BOND STREET, TORONTO 2
ORIENT LONGMANS PRIVATE LTD
CALCUTTA, BOMBAY, MADRAS
DELHI, HYDERABAD, DACCA

First published in Great Britain 1956
Second impression (with corrections) 1958
Third impression 1960
Fourth impression (with corrections) 1961

This unit has been especially written for SCIENCE ON THE MARCH by Philip E. Heafford, M.A., B.Sc., Lecturer in the University of Oxford Department of Education. The general editor of the units is Charles H. Dobinson, M.A., B.Sc., Professor of Education in the University of Reading.

All the photographs in this unit have been taken by Philip E. Heafford except where special acknowledgement has been mentioned

The first fourteen units of SCIENCE ON THE MARCH are:

1 The Air and You.
2 Water and Life.
3 The Weather and the Earth.
4 Life and Food.
5 Health.
6 Energy and Engines.
7 Hearing and Seeing.
8 Electric Currents.
9 Magnets and Electric Power.
10 Earth and Universe.
11 Heating and Cooling.
12 Birth and Growth.
13 Metals and Man (*in preparation*).
14 Atoms and Nuclear Power (*in preparation*).

[illegible] LIBRARY
Date 11.8.05
Acc. No. 11790

Made and Printed in Great Britain by Butler & Tanner Ltd, Frome and London

CONTENTS OF UNIT EIGHT

ELECTRIC CURRENTS

Problem A: HOW IS AN ELECTRIC CURRENT PRODUCED ? 8

Question 1 What are primary and secondary cells ? 9

Question 2 Can other sources of energy be converted into electricity ? 16

Problem B: HOW IS AN ELECTRIC CURRENT GUIDED ALONG A CIRCUIT ? 20

Question 1 What are conductors and insulators ? 21

Question 2 How is an electric current controlled ? 25

Question 3 What are series and parallel circuits ? 30

Problem C: HOW IS AN ELECTRIC CURRENT MEASURED ? 32

Question 1 What is current, resistance, and pressure ? 32

Question 2 What is electric power and how is it purchased ? 41

Problem D: WHAT CAN AN ELECTRIC CURRENT DO ? 46

Question 1 Can an electric current cause some metals to move ? 48

Question 2 How does an electric current produce heat ? 54

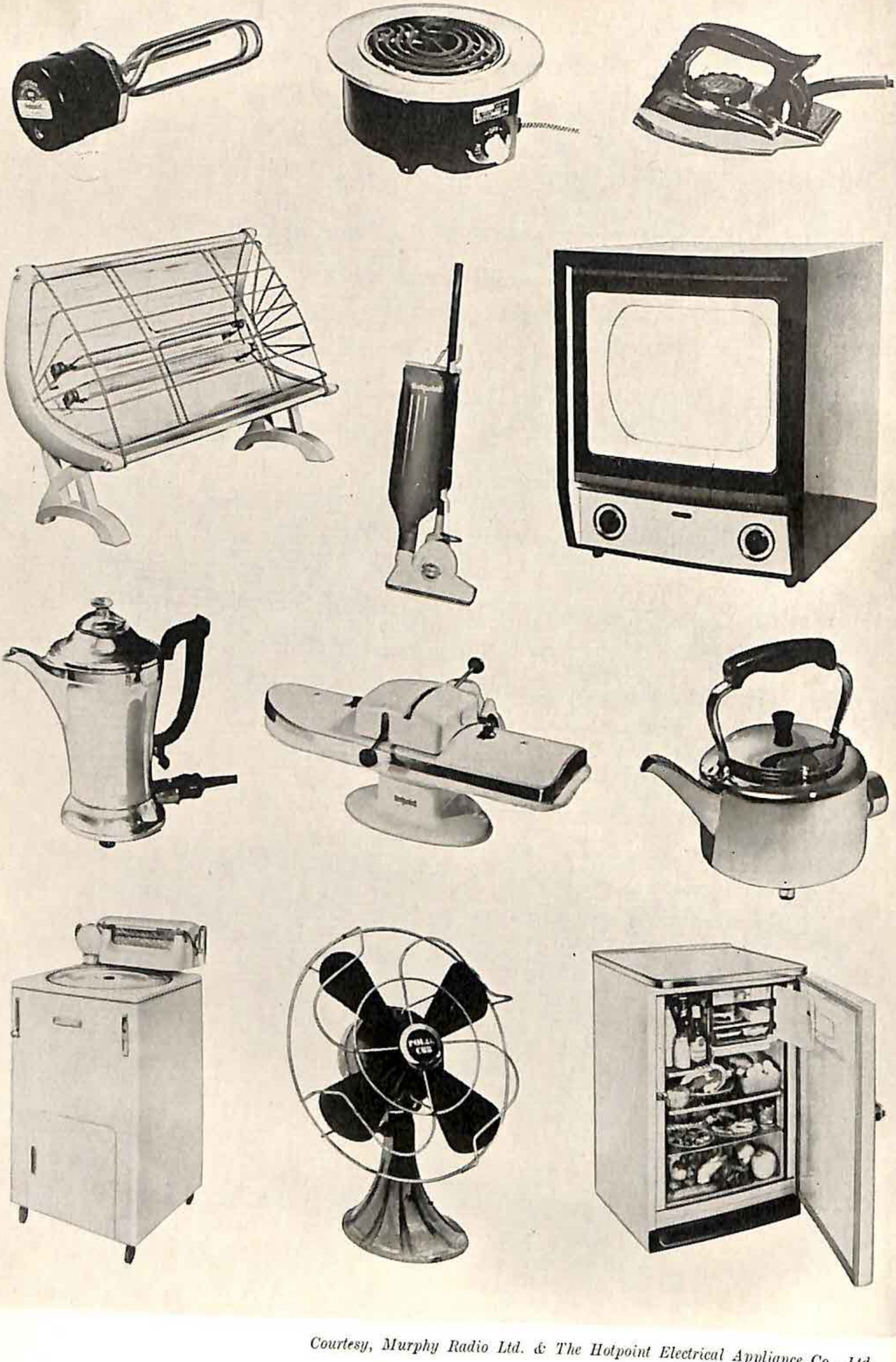
Question 3 How does an electric current produce light ? 67

Question 4 What chemical changes may take place in an electric circuit ? 72

Notes on the Unit 77

Review Questions 78

Examples to work out 79



Courtesy, Murphy Radio Ltd. & The Hotpoint Electrical Appliance Co., Ltd.

FIGURE 1.

Electricity

ELECTRICITY is a good servant of man. He uses it to help him in his work, to give him more comfort and pleasure in his home, and to look after his safety when he travels about. Let us think of some of the ways we use electricity in our daily life. We can light our rooms as we enter by the door. We light our streets, railway carriages, buses, and our aircraft. We may cook our meals by electricity and more than that we can choose either slow or rapid cooking by turning a control from OFF to LOW or MEDIUM or HIGH. We use electricity to warm our homes, supply us with hot water and to wash and iron our clothes. When we turn on our radio and television sets it is electricity which enables us to hear and see a man speaking to us from a great way off. The telephone enables us to talk to our friends when we cannot be with them, to call the police and even to listen to a voice which tells us the actual time. Because electricity travels so rapidly we hear and see these things almost as they are happening.

Do you know for what purposes all the things on the page opposite are used? More and more such things are being made to work in the service of man. Electricity is certainly keeping Science on the March.

Electricity also helps us to move about. On many railways electric motors are used to draw the carriages ; electrically operated points and electric light signals control their movements. On the roads self-operating lights control the traffic.

How many things can you think of in the motor-car itself that are worked by electricity ? It is an electric spark that sets off the explosion that drives the engine in the car. A good battery for storing and giving out electricity is a most essential part of every motor-car.

It is electrical apparatus that enables the man in the control tower to find an aircraft in the skies and to guide it to a safe landing on the runway of the airfield. It can do this from hundreds of miles away over land or sea, in fine or foggy weather.

Problem A : **HOW IS AN ELECTRIC CURRENT PRODUCED ?**

All over the world today, people are using more electricity than ever before to help them to live happy lives more easily and more comfortably. This demand has caused us to look around to find every form of energy capable of being converted into electrical energy. Some countries are fortunate in possessing tremendous resources of water power; others have coal, oil, or gas. In some places use is made of the wind, the heat of the sun, or the movements of tidal waters.

In the next few pages some of the ways of producing electricity will be described to you. You will find, however, many more and varied examples as you look at some of the wonderful machines man has invented and built.

Question I. **What are primary and secondary cells ?**

Have you taken a flash-lamp battery to pieces ? If so, you will have seen that it is made of one or more zinc metal cases. In the centre of one end of each case there is a brass cap which forms one terminal. Under this brass cap is a long rod of carbon. Zinc and carbon form the plates of this cell that produces electricity to light a miniature flash-lamp bulb. Many different pairs of metals can be used to make an electric current.

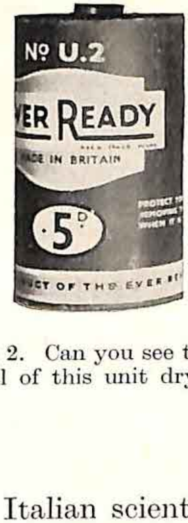


FIGURE 2. Can you see the top terminal of this unit dry cell ?

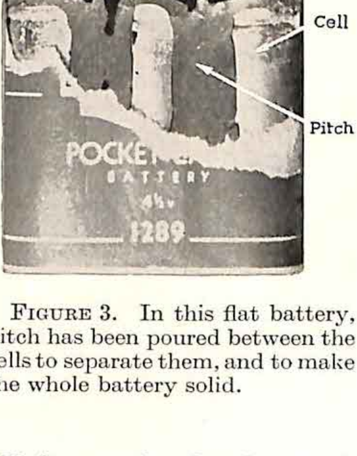


FIGURE 3. In this flat battery, pitch has been poured between the cells to separate them, and to make the whole battery solid.

An Italian scientist called Volta made the first cell by using plates of zinc and copper. He placed between these plates a piece of flannel soaked in salt solution. Then later when he tried to improve his cell he invented what we call a *simple cell*. You can make one of these cells by immersing plates of zinc and copper in a dilute solution of sulphuric acid. We name the copper plate the *positive* and the zinc plate the *negative*, and we talk of an electric current "flowing" from the positive plate round a circuit outside the cell to the negative plate. It is convenient to paint the positive terminal on the positive plate red and the negative terminal black. The liquid in the cell is split up when the current flows. This liquid is called an *electrolyte*. If you connect three of these cells together—the copper plate of one to the zinc plate of the next, as in Figure 4—you will be able to light a flash-lamp bulb.

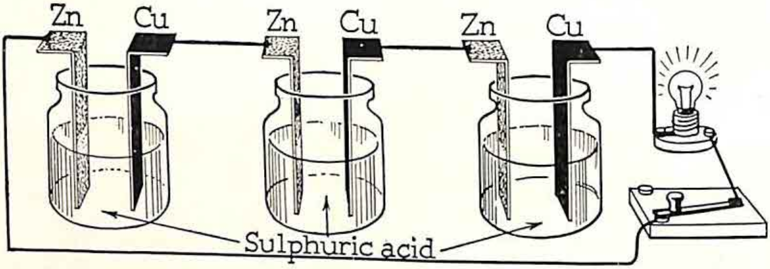


FIGURE 4. Three simple cells used to light a miniature bulb. Zn and Cu are the chemical symbols for zinc and copper.

The bulb will become dim in a few minutes' time, not because all the metal of the plates has been used, but because bubbles of the gas hydrogen will cover the copper plates. This trouble is called *polarization* :

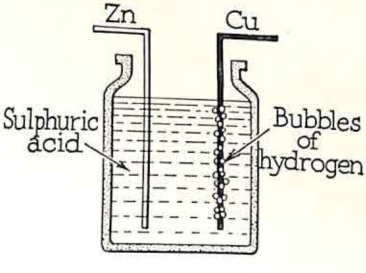


FIGURE 5. Polarization in a simple cell.

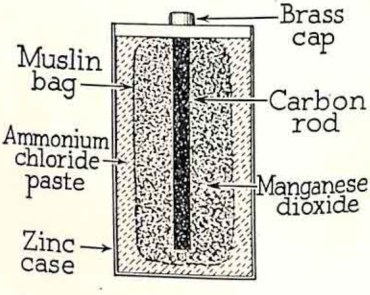


FIGURE 6. Cut section of a unit dry cell.

to avoid it various chemicals can be used to absorb the hydrogen as it forms. If you stroke these bubbles off each plate with a small paintbrush, the bulb will glow brightly again.

The Frenchman Leclanché invented a cell which is both inexpensive and lasting. He used carbon instead of copper, and surrounded this carbon plate with a long porous pot packed full of black manganese dioxide. This chemical is a depolarizer, that is a substance which prevents polarization. Instead of sulphuric acid he used a solution of ammonium chloride.

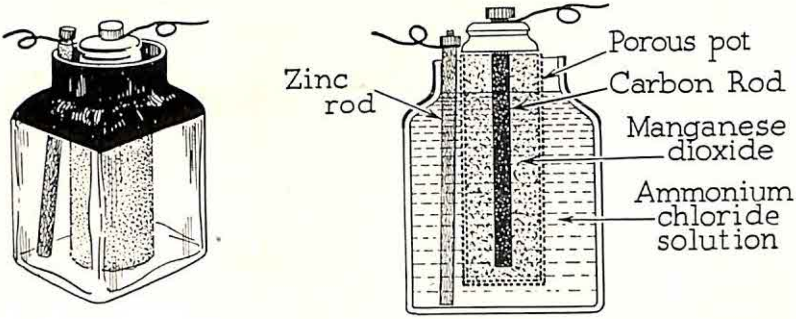


FIGURE 7. The Leclanché cell.

The dry cell in Figure 2 is really only a dry version of the Leclanché cell. The solution of ammonium chloride is made into a paste.

SOME THINGS YOU MAY CARE TO DO

1. Clean very thoroughly a penny and a silver spoon. Put one edge of the penny on one side of your tongue and one edge of the spoon on the opposite side. Nothing happens until you allow the other outer edges of the coin and the spoon to touch one another firmly. You have made a small cell with your tongue and a current flows round the outer edges. When this

current passes you feel a slight but sharp taste on your tongue.

2. Take to pieces a number of old and used batteries. It's a dirty job because very often the zinc cases of old batteries are worn and the paste begins to leak out. Count the number of cells in each type of battery and make a note of the pressure (or number of volts) the battery claimed to supply when new. Take a " high tension " battery, a " grid bias " battery, a flash-lamp battery, a bell battery and a torch battery. Divide the pressure in each case by the number of cells. What answer do you get and why ?

3. Build up three simple cells using three pieces of carbon from old dry cells and three similar pieces of zinc. Immerse them in three jam-jars and connect to a switch and a flash-lamp bulb as in Figure 4. Use ammonium chloride as the electrolyte in the jars. Switch on and watch the bulb and the plates. What is happening to the carbon ? Now switch off, take out the carbons and slide them into the centres of three manganese dioxide bags. Repeat your observation. How do you account for the steady light ?

4. Take a single dry cell to pieces and examine each part carefully. Sketch in your notebook a cross-section of the cell you examine and label your diagram.

5. Draw a diagram to show the way the different cells are connected together in a battery of many cells. How are they separated from one another ?

So far we have been concerned with *primary* cells which have produced electricity from chemicals. The materials have been changed as the electricity has been generated. If you want these cells to continue to supply electricity you must renew the original materials in them.

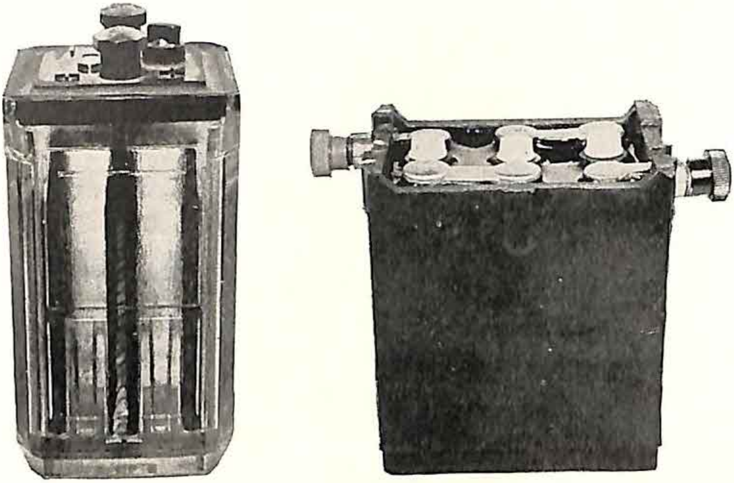
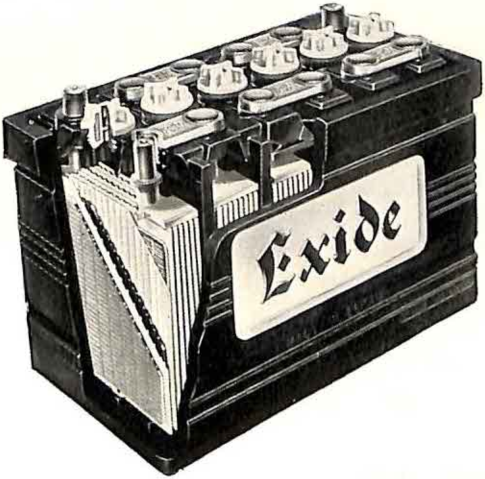


FIGURE 8. 2-volt accumulator. 6-volt motor-cycle battery.

An *accumulator* stores electrical energy. A motor-car battery is a series of accumulators connected together. This stores electricity generated by the dynamo on the engine, and gives it out again when you want it to light the lamps or turn the engine for starting. Thus an accumulator is a *secondary* cell because it supplies " second hand " electricity. If you examine the inside of an accumulator of a car battery,



Courtesy, Chloride Batteries, Ltd.

FIGURE 9. Cross-section of a multiple-plate accumulator.

you will find that there are several thin lead plates and between them thin wooden separators. (But many accumulators for battery radio sets have only thick metal plates set a distance apart.) A brown paste of lead dioxide has been pressed into one set of lead plates, and greyish powdered lead has been pressed into the other set. All these plates are immersed in weak sulphuric acid. This acid is dangerous ; it can burn your clothes and your hands.

When the engine of a motor-car is not turning and you switch on the headlamps, electricity is released from the battery. This is shown by an instrument on the dashboard called an *ammeter*. Its needle flicks over to a position of discharge (−). During this time both the lead peroxide and the powdered lead of the plates are partially converted into a whitish looking substance called lead sulphate. When the engine is started and is turning fast, electricity passes from the dynamo in the opposite direction. This causes chemical changes which recharge the battery by restoring the lead peroxide and powdered lead in the accumulators. The needle on the ammeter is then in the position of charge (+).

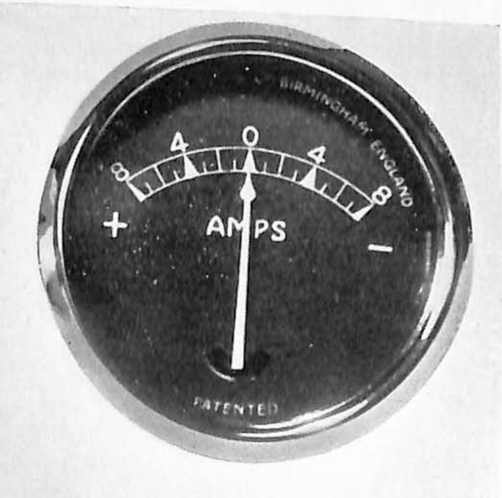
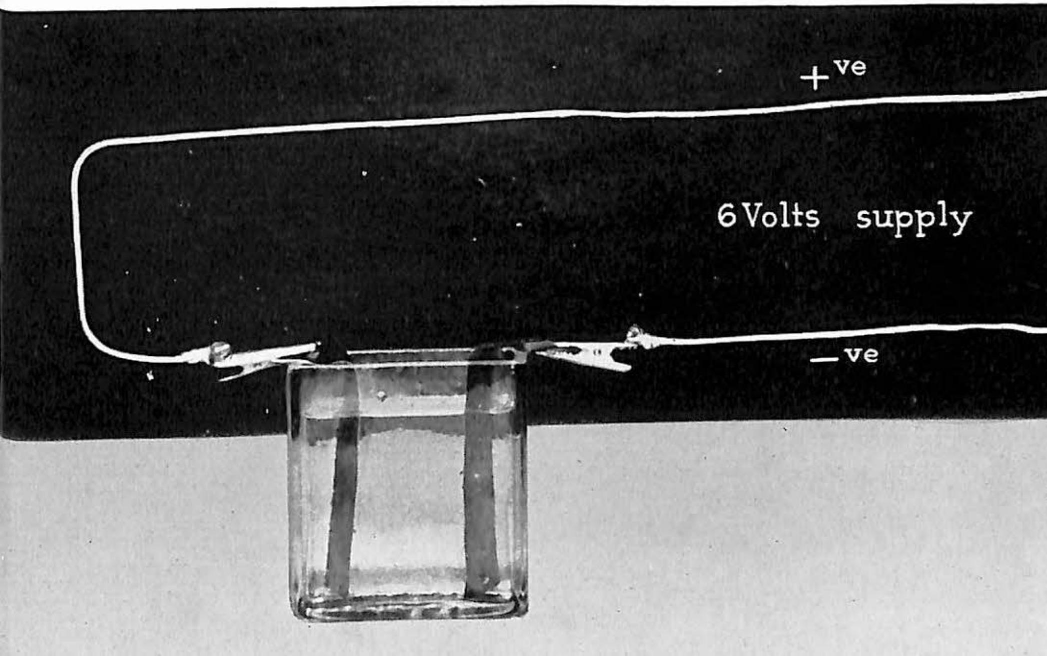


FIGURE 10. Motor-car ammeter. When the needle is to the left of the central position O, the battery is on charge (+). When it is to the right, the battery is discharging (−).

Take two plates of lead, about 2 inches wide and 4 or 6 inches long. Fasten a terminal on each near one end. Using a sharp pocket knife, rule closely spaced lines on the surface of the plates to expose the clean lead. Immerse these plates in a jam-jar filled with sulphuric acid. Your acid need not be very strong ; be careful not to spill it about. Connect this model accumulator to a source of supply of direct current of about six volts. Leave it like this for about ten minutes, and then disconnect. Mark clearly the plates connected to the positive and the negative of the supply.

What is happening to the positive plate ? What is happening on the negative plate ? Take out the plates and examine them carefully. The accumulator has been charged.

FIGURE 11. Model accumulator on charge from the direct current supply.



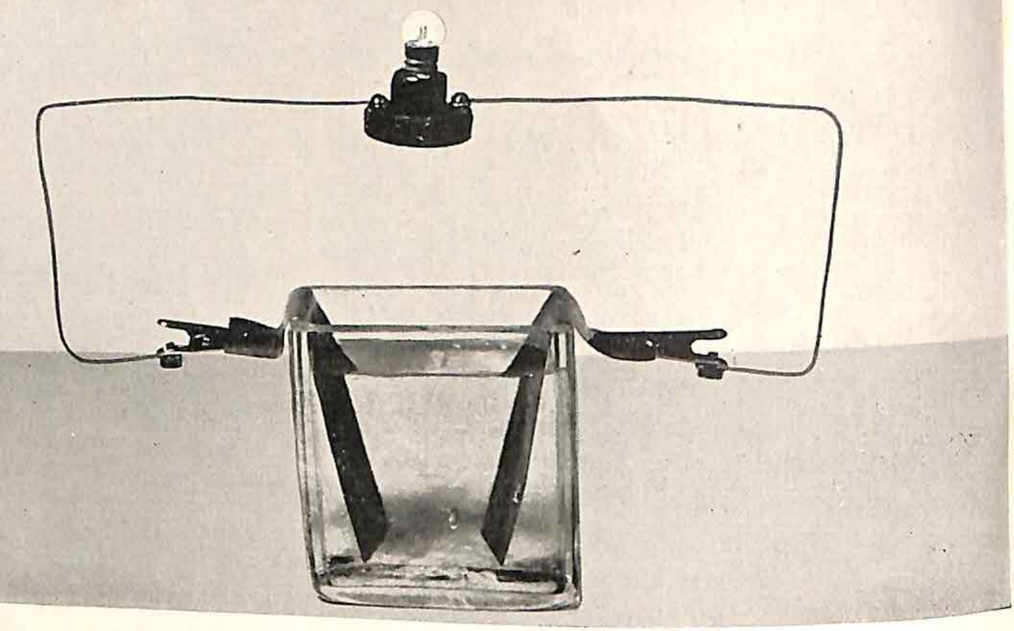


FIGURE 12. Model accumulator discharging through bulb.

Now put back the plates and connect the terminals to a small flash-lamp bulb. What happens to the bulb ? Your model accumulator is now discharged.

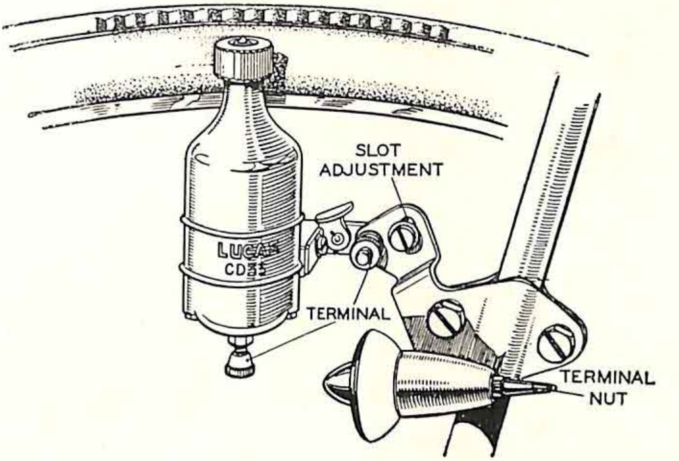
How can you increase this discharge ? What do you think would be the result of a longer charge ? What do you think would happen if you drilled a lot of fine holes in your lead plates ?

Try these experiments to see if you are correct.

Problem A: How is an electric current produced ?

Question 2. Can other sources of energy be converted into electricity ?

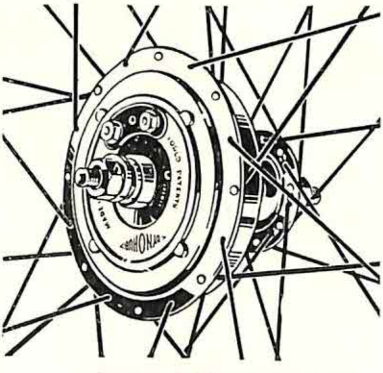
We have seen how an electric current can be produced by using up the materials, that is the metals and the liquids, of primary cells. We have seen, too, how a secondary cell can produce electricity if electricity has previously been put into it.



Courtesy, Joseph Lucas, Ltd.

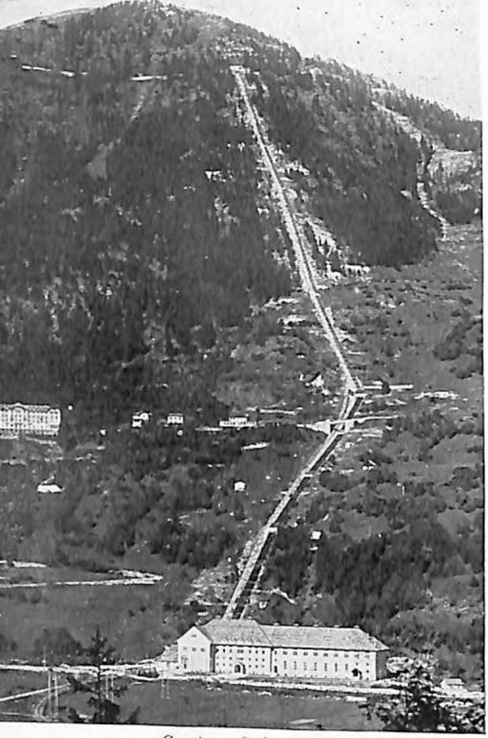
FIGURE 13. Cycle dynamo driven from tyre.

There is another way of producing electricity and that is by converting other kinds of energy into electrical energy. In Unit 6 we learnt about the many different kinds of energy. A dynamo and an electric generator are driven by mechanical energy to " generate " electricity. A small simple kind of dynamo is used on your bicycle. The tyre on the wheel turns a very small pulley wheel on the dynamo itself and electricity is produced at two terminals on its casing. (Sometimes one of the terminals is the casing itself.) You may have a dynamo built into the hub of your bicycle wheel and the slow turning of the wheel produces electricity at two terminals near the axle. What kind of energy is



Courtesy, Raleigh Industries, Ltd.

FIGURE 14. Dynamo mounted in the hub of a cycle wheel.



Courtesy, Swiss National Tourist Office

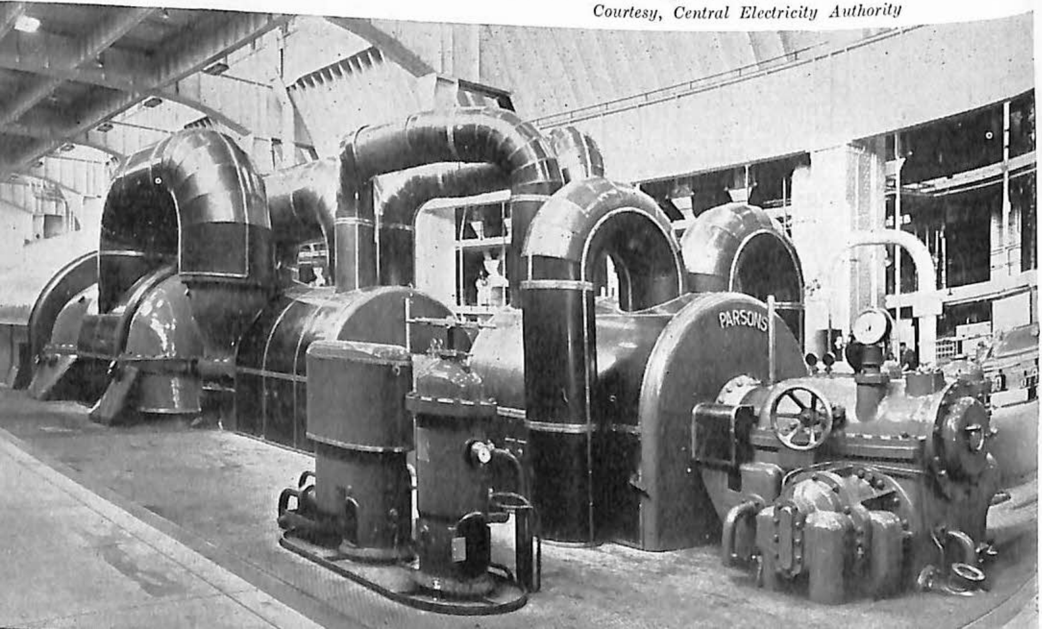
FIGURE 15. A hydro-electric power station in Switzerland. You can see the water pipe lines and the river into which the water is discharged.

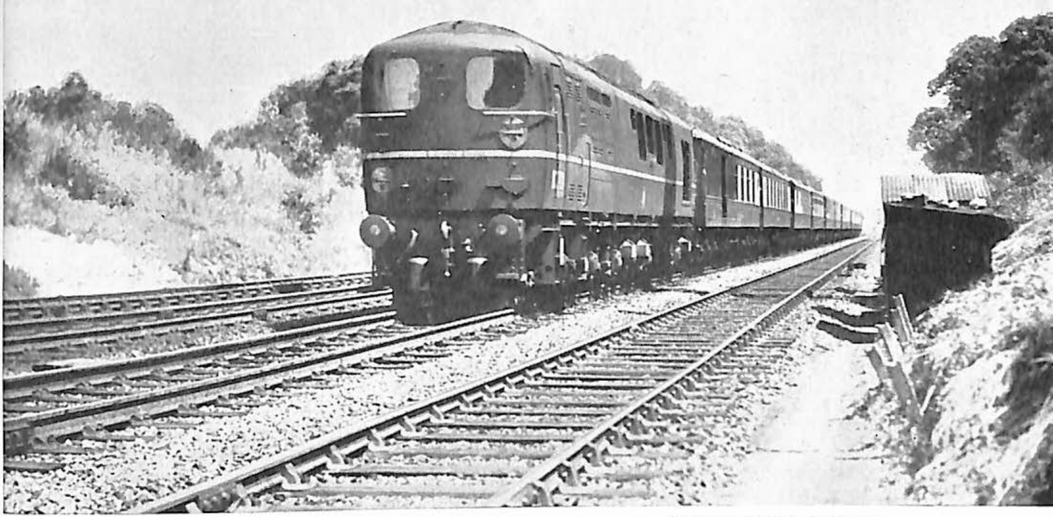
being used in this case to supply an electric current to light your bicycle lamps?

In electric power stations exactly the same process is taking place. The water of a lake or river is directed down pipes to spin a turbine, instead of being left to find its own way to sea-level. The turbine is coupled to a generator. The spinning generator produces a steady and large supply of electricity. In thermal power stations coal, oil, or gas is burnt to produce steam which drives either a steam turbine or a steam engine

FIGURE 16. A modern 60,000 Kilowatt turbo-generator of the British Central Electricity Authority. On the right is the high-pressure steam turbine, in the centre the two sections of the low-pressure steam turbine, and on the left is the electric generator.

Courtesy, Central Electricity Authority





Courtesy, British Railways

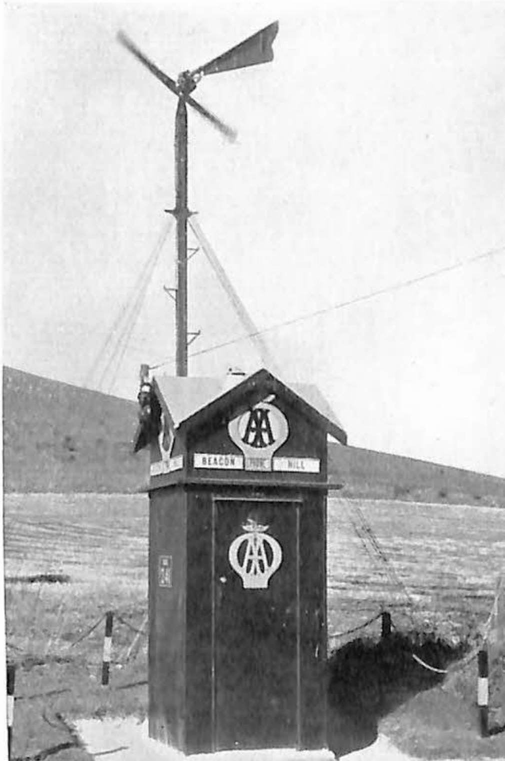
FIGURE 17. Down "Bournemouth Belle" hauled by a British Railways diesel electric locomotive.

coupled to the generator. The electricity eventually passes out of the power house along the cables which we see hanging on the pylons across the countryside.

Many countries now have diesel electric locomotives on their railways. Energy from the explosion of heavy fuel oil drives a diesel engine which turns a dynamo inside the locomotive itself. The electricity from this dynamo is then supplied to electric motors that drive the axles.

So we have learnt that some sources of energy—running water, coal, oil, gas, wind, and now nuclear energy—can be converted into electricity.

FIGURE 18. Wind generator of electricity.



SOME THINGS TO THINK ABOUT

1. Why is the wire from the battery of a motor-car to the self-starter motor very thick, whereas the wires to the car headlamps are much thinner ?

2. Why are accumulators, rather than dry cells, used in car batteries ?

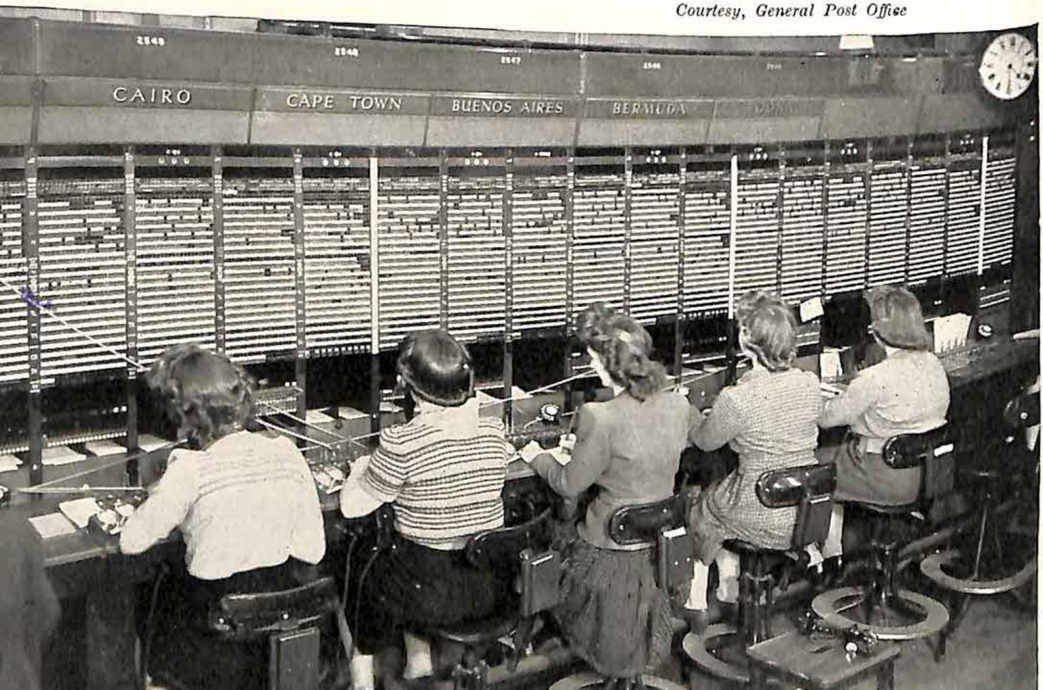
3. How many different kinds of energy can be converted to electricity ? Make a list of these, the ways in which they are converted, and the uses to which the electricity is put.

Problem B : HOW IS AN ELECTRIC CURRENT GUIDED ALONG A CIRCUIT ?

You know that you cannot use a telephone until it is connected with two wires running overhead or underground to an exchange. You know also that electricity enters your house by a cable of two wires

FIGURE 19. International Telephone Switchboard.

Courtesy, General Post Office



which may be suspended overhead or buried in the ground. On your bicycle you may have fitted either a battery or a dynamo, and a wire leads from one of these to a front lamp and a rear lamp. Sometimes there are two wires and sometimes only one. How do you account for this difference ?

Electricity can only flow in a circuit if it has no gaps in it at all. Such a circuit is called a *closed* circuit. In the same way blood flows through the body in a continuous closed circuit of arteries and veins.

Problem B: How is an electric current guided along a circuit ?

Question 1. **What are conductors and insulators ?**

If we wish to use the electricity we have generated to heat a bar of an electric fire in our house, we must join the generator to the bar by some material in the form of a circuit. The material of the circuit must be able to conduct electricity to and from the bar. Materials which conduct electricity easily are called *conductors* and those that do not conduct electricity easily are called non-conductors or *insulators*. Many materials can act as conductors, and many materials can act as insulators. Some materials make much better conductors than others.

SOME THINGS TO FIND OUT

1. Connect the two terminals of a flash-lamp battery by means of copper wire to the two terminals of a miniature bulb. The bulb will light brilliantly. Take off part of one of the copper wires and replace it by a few other substances to find out which are conductors and which are insulators. Try cotton, string, glass, an iron nail, a brass screw, a rubber band, an aluminium

[illegible]
Date ... 11.8.05
Accn. No. 11790

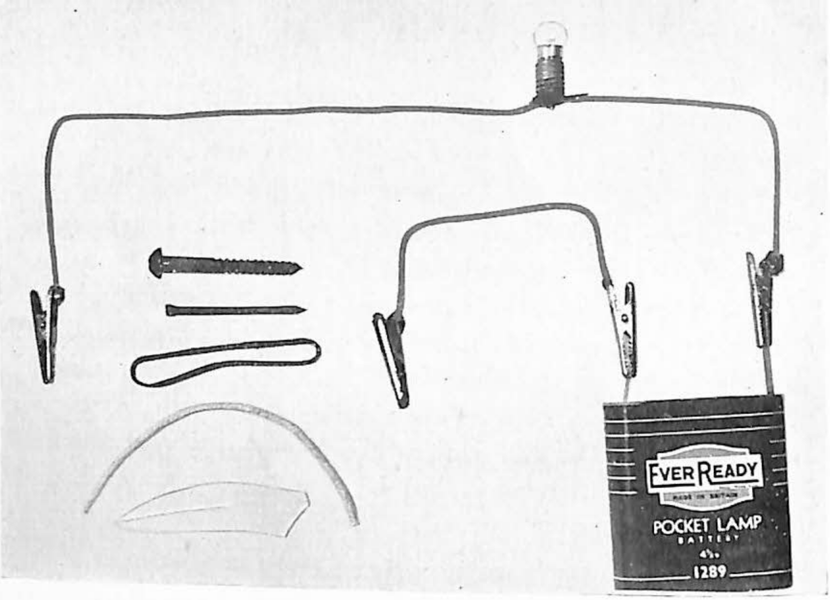
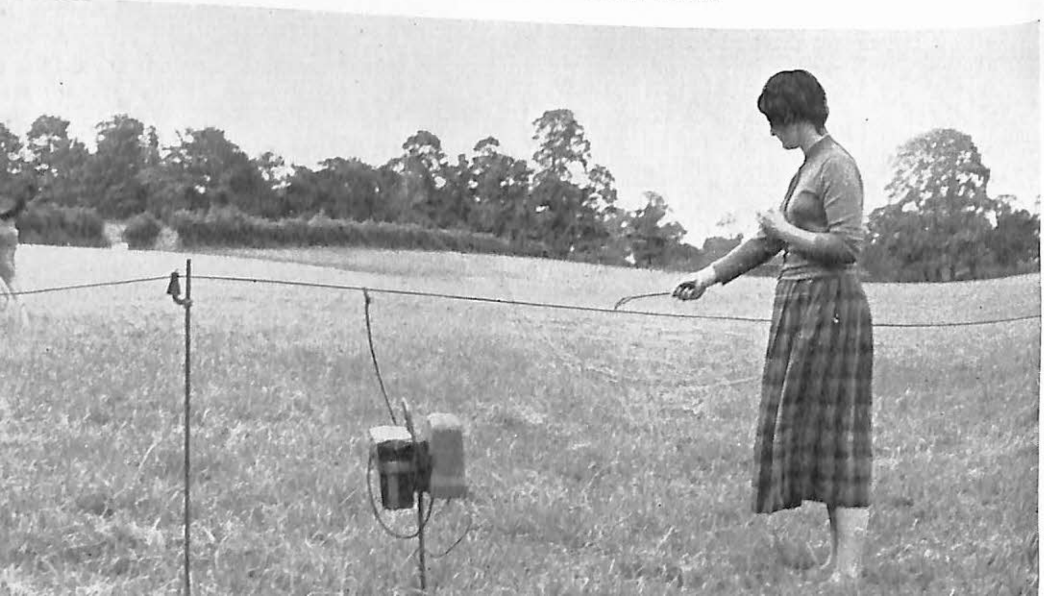


FIGURE 20. Testing circuit for conductors.

saucepan, the lead of a pencil (which is a mixture of clay and graphite), and as many metals as you can obtain. Make a list of those materials that conduct electricity and light the bulb, and put all the other materials in another list called insulators.

2. Approach a farmer's electric fence which is working. Hold a few long substances in your hand and

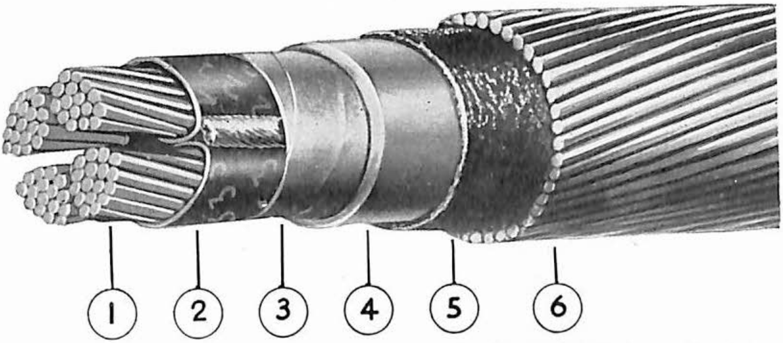
FIGURE 21. Electric cattle fence.



allow them to touch the wire. You will soon know which are the better insulators. Try the things in the list below in the order in which they are given. Are the ones at the end of the list better conductors? You may find that those near the end of the list conduct electricity too easily for you to hold.

(*a*) Dry straw.
(*b*) An oak branch.
(*c*) A willow branch.
(*d*) A walking stick.
(*e*) A folded newspaper.
(*f*) A length of dry string.
(*g*) A leather strap.
(*h*) A length of cord.
(*i*) A length of damp string.
(*j*) A piece of green grass.

3. Obtain as many different small pieces of cable as you can. Cut a number of these cleanly with a pair of metal shears. Draw in your notebook the cross-sections of some of them, showing clearly the different insulators used and the arrangement of the individual wires of the conductors. Figure 22 shows the cross-section of a large cable. Can you see the separate conductors?



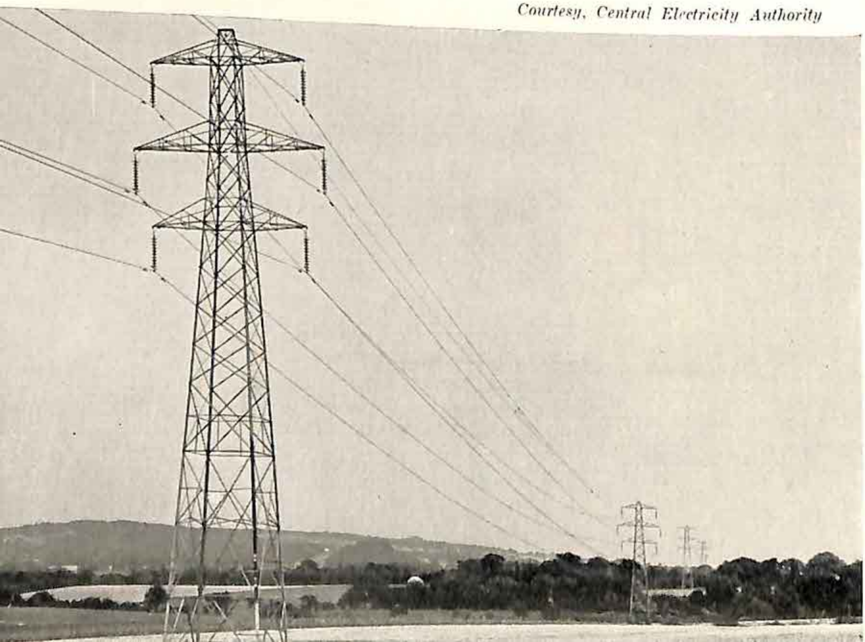
Courtesy, British Insulated Callender's Cables, Ltd.

FIGURE 22. A four-core 660-volt electric cable showing—(1) the four copper conductors; (2) numbered paper insulation; (3) paper insulation; (4) metal protecting sheath; (5) pitch; and (6) outer protective layer of steel wires.

With the aid of conductors and insulators we can understand how a circuit can lead electricity from a generator to the bar in our electric fire, though the simple tests were not accurate enough to tell us which were the best conductors and which were the best insulators. We were only able to get rough ideas. The human body is a good conductor of electricity; that is why it is very dangerous to touch conductors connected to the mains supply. We try to avoid this kind of accident by surrounding all house wires with good insulators and putting covers on the holes of any exposed electric socket. The good conductors that we make use of today are copper (which is reasonably strong and cheap), aluminium (which is light), and carbon. The good insulators are glass, porcelain, silk, cotton, paper, wax, plastic, polythene, rubber, and air—which is very good when it is dry. So we shall use conductors to carry the electricity where we want it to

FIGURE 23. High-tension transmission lines carrying electricity from generating stations are suspended by long porcelain insulators from tall steel pylons.

Courtesy, Central Electricity Authority



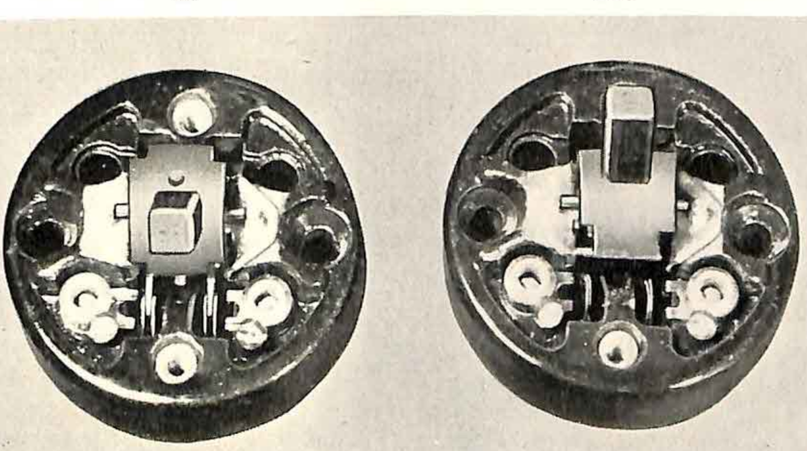
go, and we shall use insulators to prevent it from leaking and flowing where it should not go. Thus we cover copper wires with silk, cotton, rubber, or plastic. All these varieties of coverings are produced and sold for our safety. D.C.C. copper wire means double cotton covered copper wire.

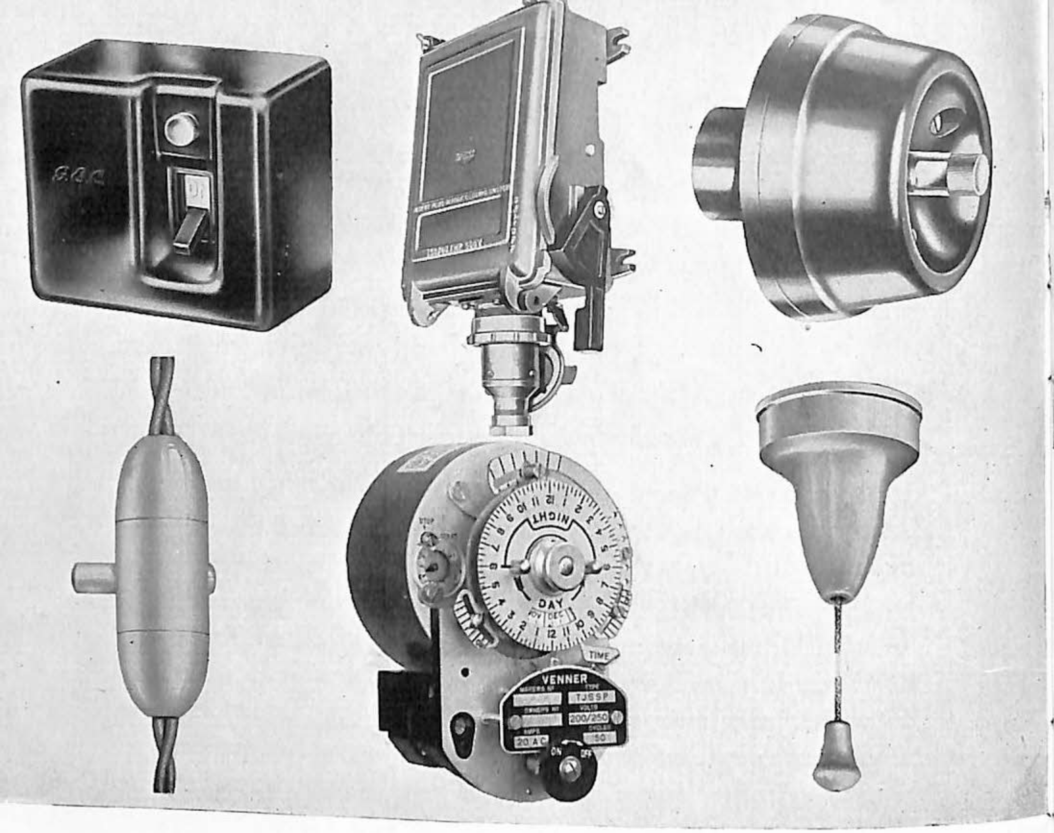
Problem B: How is an electric current guided along a circuit ?

Question 2. **How is an electric current controlled?**

There are many ways of controlling an electric current, as we call electricity flowing in a circuit. We may want to stop the current altogether, or turn it on and off at will. For this purpose we use one of the many kinds of *switches*. An electric switch in its OFF position breaks the circuit by leaving a gap of air between two copper springs. In its ON position it places a strong and good conductor between the springs. Some switches have strong springs which snap the conductor quickly out of the circuit when it is broken. You can hear the sharp click. Other switches have a neat silent movement which breaks and makes the circuit.

FIGURE 24. Switch positions.





Courtesy, Venner Ltd. & The General Electric Co., Ltd.

FIGURE 25. Different types of switches.

The bell push only allows current to pass when it is pressed. The delayed action switch stops the current flowing after a certain interval of time. The time switch stops and starts the current flowing at certain fixed hours of the day or night. Where have you seen these switches at work?

SOME THINGS YOU MAY CARE TO DO

1. Trace the circuit taken by the electric current on your bicycle. Ask permission to examine a bicycle fitted with a battery; then one fitted with a dynamo; and finally one fitted with a battery and a dynamo.

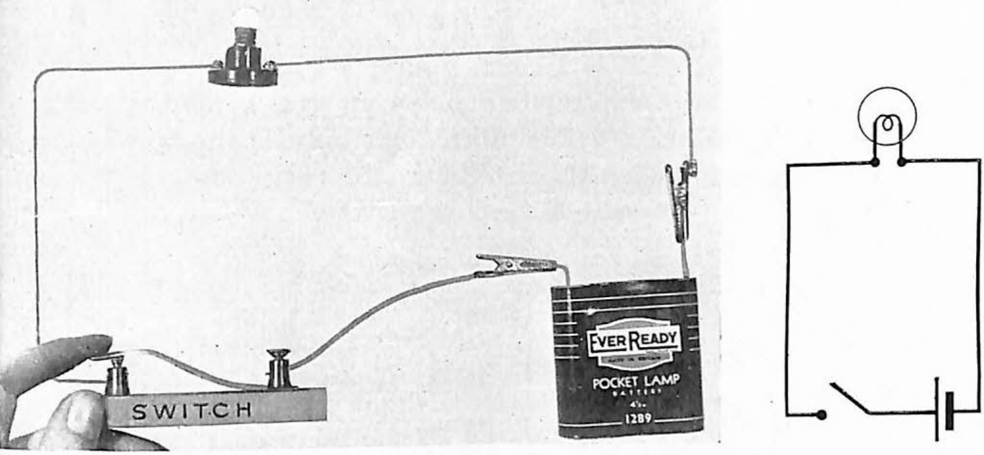


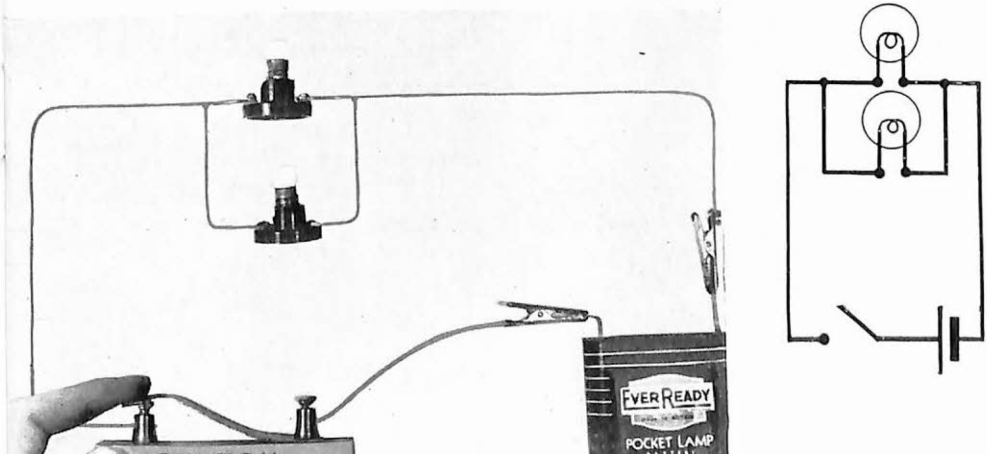
FIGURE 26.

How do you show (*a*) bulb, (*b*) switch, (*c*) battery, in a wiring diagram ?

2. Examine a number of bulbs and sketch the circuits which the electricity takes in passing through them.

3. Obtain a single accumulator or a flash-lamp battery, several long lengths of insulated copper wire, two flash-lamp bulbs in their holders, and two ordinary switches. Construct the circuits shown in the diagrams and photographs of Figures 26 and 27. The diagrams on the right are called wiring diagrams and the photograph opposite each diagram shows how the apparatus is arranged.

FIGURE 27.



4. Construct the circuits shown in the next two wiring diagrams. In Figure 28 one bulb is lit from either of two switches. In Figure 29 each bulb has its own separate switch to control it.

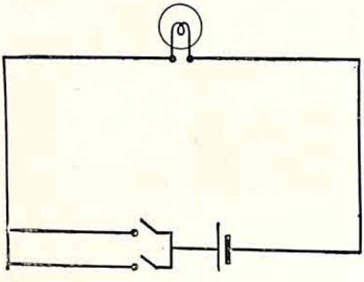


FIGURE 28.

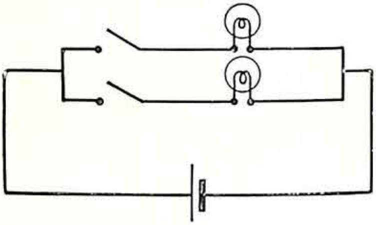


FIGURE 29.

5. Add two two-way switches to your apparatus.

Examine carefully a two-way switch to find out how the electric current can pass through the switch when the knob is in one position, and when it is in the other position.

Set up the circuit shown in the wiring diagram of Figure 30 in order to light a bulb and to turn it off again from either of the two two-way switches.

Is there an arrangement like this anywhere in your home ?

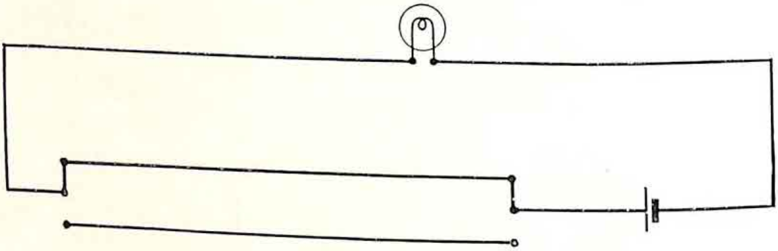


FIGURE 30.

6. Examine an intermediate or cross-over switch to trace the course of the electric circuit between the four terminals in both positions of the knob.

Cut the two wires joining the two two-way switches in the circuit of the wiring diagram of Figure 30 and insert the cross-over switch between these two switches.

Can you light and extinguish the bulb from three positions ?

Figure 31 below shows how the cross-over switch works.

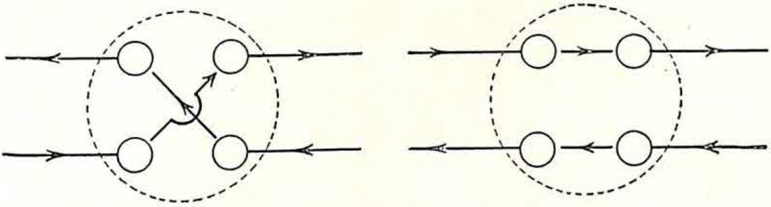
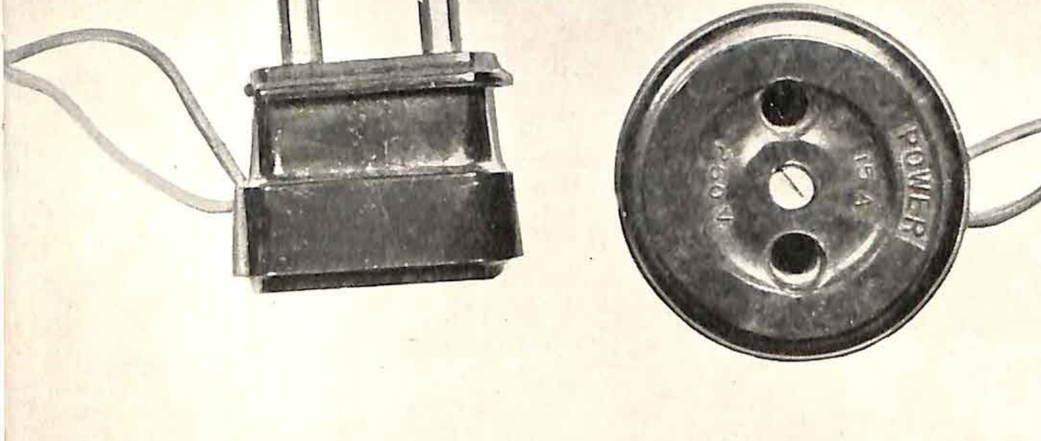


FIGURE 31.

7. Obtain one two-pin socket and one two-pin plug that fit one another. Make your own cross-over switch by fixing two leads into the plug and two leads into the socket. To cross-over the switch remove the plug and insert it in the socket in the opposite direction.

FIGURE 32. You can use this plug and socket as a cross-over switch.



Question 3. **What are series and parallel circuits ?**

There are many ways of connecting up an electric circuit and distributing the electricity for our use.

For instance, when you connected the battery, switch, and bulb as in the wiring diagram of Figure 26, these items are said to be connected in *series*.

Now look at the wiring diagram of Figure 28. The two switches are connected in what is known as *parallel*, that is, the current can pass through either switch to light the bulb.

In the circuit of the wiring diagram of Figure 27, the two bulbs are also in parallel, so that both of them can be lit from the same battery and switch.

Figure 29 shows a circuit in which both switches and bulbs are in parallel, so that the electricity can pass through one bulb and its switch and the other bulb and its switch, either at the same time or independently of one another. It is useful in some electric circuits to have some appliances in series and others in parallel. The cells of a flash-lamp battery and the cells of a motor-cycle battery are connected in series as you will see from Figures 3 and 8. The lamps, heaters, and other electrical appliances in our homes are connected in parallel.

Electricity arrives in a house through a large cable from the generators of a power station. It is then conducted from the first mains fuse to the meter, the mains switch, and the distribution board. The mains fuse protects the whole of the circuits in the house ; the meter measures the electricity supplied to the whole house ; and the mains switch cuts off the supply

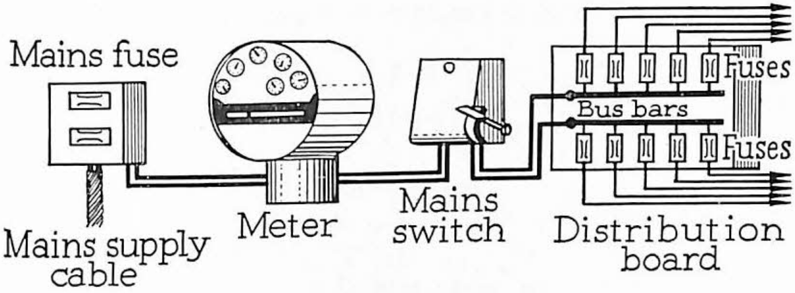


FIGURE 33. The supply of electricity to a house. Wires lead in pairs from the distribution board to form the parallel circuits of the house.

to the whole house. All these are connected in series. There are two thick copper bars, called bus bars, on the distribution board. From these bus bars a number of circuits in parallel are led to various parts of the house. The circuits conduct electricity to the lamps, cookers, heaters, and other appliances. They are connected in parallel so that each appliance can be used independently of the others.

SOME THINGS YOU MAY CARE TO DO

1. A helpful owner of a car may be able to show you the diagram of the electric circuits of his car. You may be able to follow the parallel circuits leading to the lamps at the front of the car. It is difficult to follow more than a few of these in such a small space.

2. Can you draw a wiring diagram showing the circuits by which electricity is distributed to the rooms and passages in your home ? (Remember that it is very dangerous to touch any of the conductors carrying electricity from the mains supply.)

Problem C: HOW IS AN ELECTRIC CURRENT MEASURED?

Often we hear our friends asking about the electrical equipment in their homes in this way: "Can I take this off the light socket?" "Will you buy me a 100-watt lamp? I can't see for sewing with that 40-watt lamp in there." "Switch on both bars of the fire in the bedroom." "This plug won't fit; it is too big—the bedroom has only a 5-amp socket." "I suppose you have 240 volts in your house." "The electricity bill came today and we've used 810 units, 421 units for water heating, 326 for cooking and only 63 for lighting. How do they work this sum out?" "Look what it costs!"

What does all this mean? In this problem we shall learn how to make an instrument for measuring the strength of an electric current, and then we shall learn what these units, watts, amps, and volts mean. At the end of the problem we should be able to calculate the cost of using a piece of electrical apparatus for any length of time.

Problem C: How is an electric current measured?

Question 1. What is current, resistance, and pressure?

Electricity will not flow along the wire of a circuit unless you place across the ends of the wire some pressure or force. The usual force is provided by an electric cell, accumulator, or mains supply. Thus before an electric current can flow we must have what we call an *electric pressure*. Scientists call it an *electro-motive force* (E.M.F.); this is, a force which causes the electricity to move. An E.M.F. always exists at the terminals of an electric cell ready to drive electricity round a circuit. This flow of electricity or electric current can be directed to do one of several things. It may be used to heat an electric fire or to light a lamp. It may exert a force upon soft iron held near to the wire through which the current is passing. We can, in fact, measure the strength of an electric current by measuring the force that it exerts upon soft iron.

Your teacher will help you to construct the next piece of apparatus. Perhaps several of you can join together to make it, each doing a part of it. When it is finished you can all use it to measure the strength of an electric current.

Wind carefully 400 turns of Number 26 Standard Wire Gauge (S.W.G.) enamelled copper wire on a former in the shape of a bobbin. The former can be made of thin card. Bind these turns of wire on the former with some adhesive tape to form a neat coil. The former should have a smooth central hole, about $\frac{1}{2}$ inch in diameter, into which a fat soft iron nail should

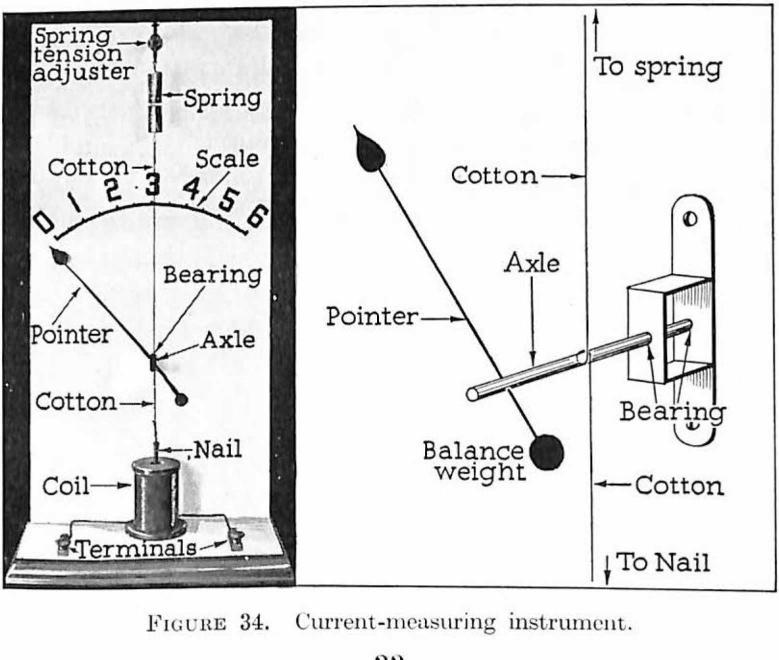


FIGURE 34. Current-measuring instrument.

be able to slide quite easily. Suspend the nail, so that the end of it hangs just inside the hole, by a long piece of cotton round an axle which can turn freely in a Meccano bearing. Mount the finished coil and the bearing on a vertical board as shown in Figure 34. The other end of the cotton is attached to a fine long coiled spring. To the axle fit a pointer and on the board mark a scale. Adjust the pointer to the zero position on the scale. You have then completed your construction of a simple current-measuring instrument.

Connect this instrument in series with a motor-cycle battery and a car sidelamp bulb. As soon as the current flows to light the bulb, the coil of wire, through which the current is also passing, will draw the nail into its central hole. The cotton will pull on the axle, turning it and the pointer until the instrument indicates a certain reading on the scale. The force of attraction of the coil for the nail when the current flows is balanced by the force needed to extend the spring to the point shown on the scale.

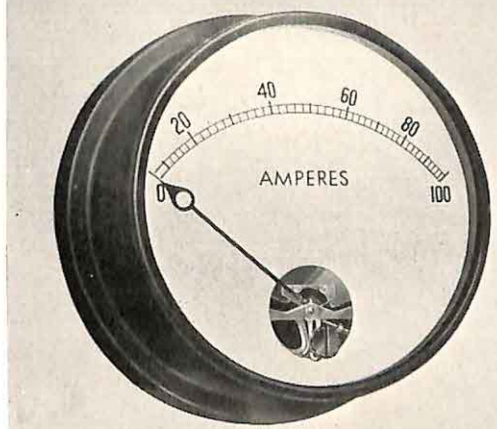
Repeat the experiment using one battery and two sidelamp bulbs in series. Do you find that you have now nearly half the reading on the scale ? In Unit 6 we learnt that the extension of a spring depends exactly upon the force which pulls it. Half the extension of the spring is caused by half the force. Thus you have measured a second current which caused a force of attraction about half as strong as the first. In other words we say that the strength of the second current is half the strength of the first current.

Repeat the experiment using two batteries and two sidelamp bulbs in series. What is the reading on the scale this time ? Can you account for this ?

You will find if you repeat these three experiments with the current flowing through the coil in the opposite direction that you obtain the same readings. Reverse the connections to the coil and try this. To be able to measure the strength of a current by the same instrument whatever its direction of flow is most useful. In our houses the electricity we use flows in one direction and then reverses in the opposite direction. It does this one hundred times a second. Such a current which alternates one way and the other is called an *alternating current*. We shall study this type of current more thoroughly in Unit 9. A practical current-measuring instrument, constructed with soft iron moving inside a coil, could therefore be made for use with the domestic mains supply of electricity.

We have seen how we have been able to measure the strength of an electric current with our apparatus simply by using small extensions of a spring. An electrical engineer would find it inconvenient to carry an instrument of this kind to measure an electric current. So a smaller and more robust meter has been designed. This measures the electric current passing through it in units of one *ampere*. (André Marie Ampère was a French mathematician and scientist.) This meter is called an *ammeter* and in it the force exerted on a soft iron rod, by an electric current flowing in a coil, is balanced against a spring. More accurately it should be called a moving iron ammeter. Figure 35 shows such an instrument. Thus for all practical purposes electric currents are measured in amperes by an instrument very similar to the one you constructed.

FIGURE 35. A moving iron ammeter is an instrument to measure the strength of a direct or alternating electric current.



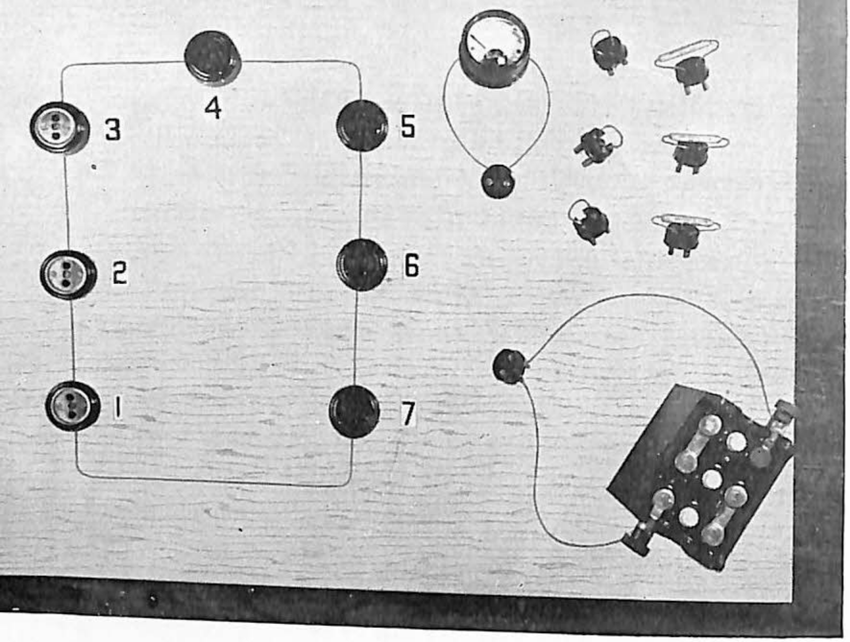


FIGURE 36. The circuit board.

SOMETHING TO FIND OUT

Several of you can join together to construct an electric circuit. Connect seven two-pin sockets in series on a large board as shown in Figure 36. Turn four two-pin plugs into straight-through plugs by connecting pieces of copper wire across the terminals of their pins. Connect two-pin plugs to an ammeter, three resistors, and three motor-cycle batteries. A resistor is something that hinders the flow of an electric current. Your teacher will be able to select suitable wire resistors and an ammeter. You will soon learn what is meant by the values of the units used to describe the resistors and the ammeter. (Try either 100-ohm resistors with a 100-milliampere ammeter or 3-ohm resistors with a 5-ampere ammeter.) You have now arranged a series circuit so that you can put in batteries, ammeter, and resistors wherever you wish

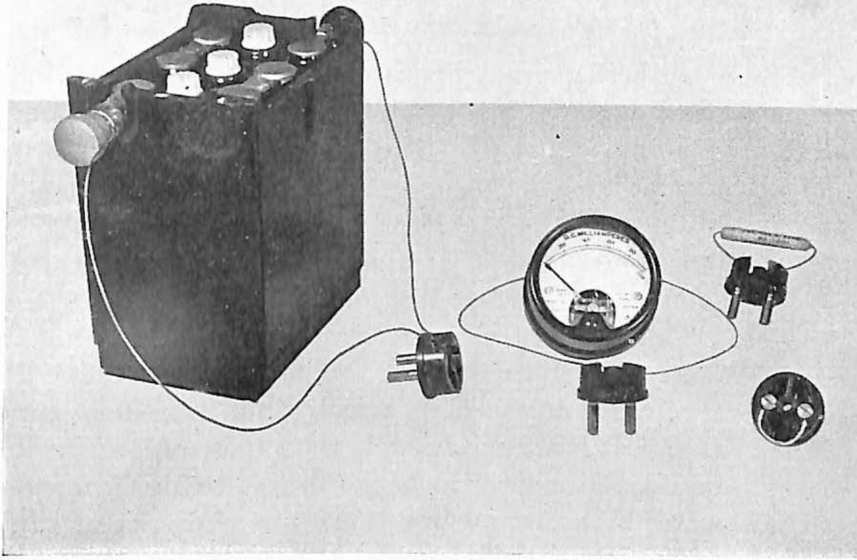


FIGURE 37. Details of plugs.

and fill in the other spaces with straight-through plugs. Figure 37 shows how a battery, the resistors, and the ammeter are connected to two-pin plugs.

Put one of the batteries in position 1, one of the resistors in position 5, and then the ammeter into any one of the remaining positions. Fill the other positions with straight-through plugs. Note the current measured by the ammeter in any of its positions. If the current is the same at all points in the circuit, then this means that the current does not disappear as it passes through a resistor, but flows all the way round the circuit and does not pile up anywhere.

The movement of electricity along a wire appears to be similar to the movement of water flowing down a pipe. The water in the pipe may well meet obstacles in its path, such as valves and taps, which resist the flow of the water. The smaller the hole in the tap the bigger the resistance offered to the water current. Does the same thing happen in electricity?

SOMETHING ELSE TO FIND OUT

With the same apparatus as in the last experiment, insert a second and a third resistor in the series circuit. Has the addition of the second resistor reduced the current flowing round the circuit ? And has the addition of the third resistor reduced it still further ? Does this mean that the greater the resistance, the smaller the current ?

Think again of the water in the pipe, flowing from the reservoir to the sink. The water is pumped into the reservoir which is usually built on high ground. It flows downhill through the pipes, out through the tap, and then through the drains to the level of the water table from where it is pumped up again. In the case of the electric current the electricity flows around the closed circuit through the resistors and back again to the battery where it is pumped up to start on its journey through the circuit once more. This pumping by and through the battery is giving the electricity its pressure.

Electric pressure is the force that drives the electricity through the resistance in the circuit. The greater the electric pressure that the battery can provide, the greater the push it can give to the electricity on its journey around the circuit.

SOME OTHER THINGS TO FIND OUT

1. Does a greater electric pressure drive a bigger current through the same resistance ?

In the series circuit place three resistors in positions 5, 6, 7, and place one of the batteries in position 1, as shown in Figure 38. Note the current flowing by reading the ammeter in position 4. Find what current flows when a second battery is added in position 2, and again when a third battery is added to the

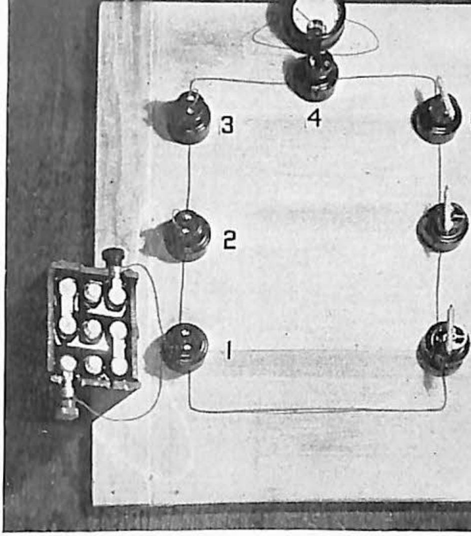


FIGURE 38.

previous two in position 3. How has the current increased as the number of batteries increased from one to two, and then to three ?

We conclude from this experiment that if the resistance in the circuit is kept the same, a greater electric pressure causes a greater current to flow in the circuit. We are now in a position to express these results in the form of a simple equation. This was first stated by a German scientist Georg Simon Ohm who lived from 1787 to 1854.

$\frac{\textbf{Pressure}}{\textbf{Current}} = \textbf{Resistance}$ (which remained constant)

2. Does a greater electric pressure drive the same current through a greater resistance ?

Place one battery in position 1, and one resistor in position 5. Measure the current. Then place two batteries in positions 1 and 2, and two resistors in positions 5 and 6. Again measure the current. Now place three batteries at 1, 2, 3, and three resistors at 5, 6, 7 ; once more measure the current flowing.

From the measurements of the currents flowing during these three experiments we conclude that a greater electric pressure will send the same current through a greater resistance. These results may be expressed by a similar simple equation.

$\frac{\textbf{Pressure}}{\textbf{Resistance}} = \textbf{Current}$ (which remained constant)

The resistance offered by one resistor is a fixed amount. So the resistance offered by three equal resistors, connected in series, is three times this amount. The resistance of a resistor, or any other piece of electrical apparatus, is measured in units of one *ohm*, so called in honour of this German scientist. Thus we have two units which are quite definitely fixed—the ampere or unit of current, and the ohm or unit of resistance. Using these two fixed units we can, therefore, fix our unit of electric pressure so that the equation remains true. This unit of electric pressure is called a *volt* in memory of the Italian professor Alessandro Volta. The important equations can now be written conveniently as :

$$\textbf{Current in amperes} = \frac{\textbf{Pressure in volts}}{\textbf{Resistance in ohms}}$$

Hence a pressure of one volt will drive a current of one ampere through a resistance of one ohm.

SOMETHING YOU MAY CARE TO DO

Complete the following table and add other examples.

Appliance	Pressure in volts	Current in amperes	Resistance in ohms
Cycle bulb	6	0·5	
Car sidelamp . . .	12		24
Torch bulb		0·25	13
Radio	240	0·25	
Television	240	0·60	
Iron	240		120

Question 2. **What is electric power and how is it purchased?**

You will require three motor-cycle batteries, nine car sidelamp bulbs, and a moving iron ammeter reading from 0 to 2 amperes. Probably the current-measuring instrument you constructed in Question 1 will work well as this ammeter. Your teacher will be able to tell you if this is so and also if your batteries and bulbs are suitable. (The motor-cycle batteries of 6 volts will work well with 6-volt 3-watt car sidelamp bulbs.) Connect all these to two-pin plugs. Then construct, on the end of the series circuit, two parallel circuits each with three sockets as shown in Figure 39.

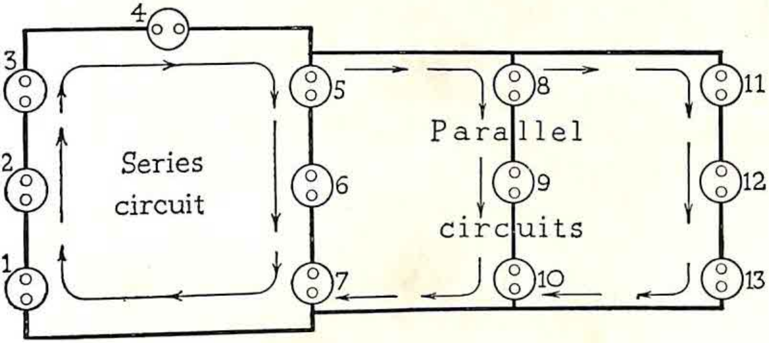


Figure 39. The circuit board.

In the series part of the circuit put one battery, one bulb, and the ammeter in positions 1, 5, and 4. Put straight-through plugs in all the other positions in the series circuit, but none in the parallel circuits. Notice that the bulb is fully lit. Stick a label over the scale of the ammeter, and on the label make a new scale to measure current in special units to suit our experiment.

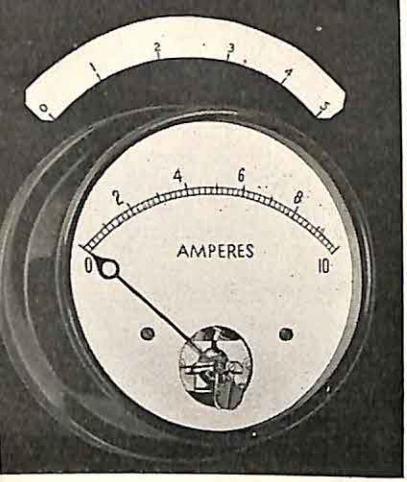


FIGURE 40. Putting a special scale on an ammeter.

The zero mark 0 of our new scale must be at the same place as the zero mark 0 of the real scale. Unit 1 on our special scale is put at the position shown by the needle of the instrument when one bulb is lit from one battery. You can mark units 2, 3, 4, etc., across the special scale at equal scale divisions from each other, as on the real scale. You are now ready to measure in *our* own units the current required to light various bulbs from one or more batteries.

Make a table as shown on page 43 in your notebook. Place the bulbs, batteries, and straight-through plugs in the sockets indicated in columns 1, 2, and 3. What happens if a battery plug is put in the reverse way round ? Write in column 4 the number of bulbs fully lit. Measure the current flowing in each case and mark that in column 5. In column 6 write the number of batteries in series used in the circuit. This number can be taken as the number of our units of pressure. Thus in our experiment both the current and pressure are measured in our own units and not in the standard units of amperes and volts. Multiply the current by the pressure and write the product in column 7. What do you discover from these experiments ? Can you explain this ?

The second important relation between electrical units is suggested as a result of these experiments—a relation that we shall often want to use. A certain quantity of electrical energy is converted every second into heat and light energy in the bulbs. Electrical power is needed to light the bulbs. The power required

(1) Bulbs placed in sockets numbered	(2) Batteries placed in sockets numbered	(3) Straight-through plugs placed in sockets numbered	(4) Number of bulbs fully lit	(5) Current in our units	(6) Pressure in our units	(7) Current × Pressure in our units
5	1	2, 3, 6, 7	1		1	
5, 8	1	2, 3, 6, 7, 9, 10	2		1	
5, 8, 11	1	2, 3, 6, 7, 9, 10, 12, 13	3		1	
5, 6	1, 2	3, 7	2		2	
5, 6, 8, 9	1, 2	3, 7, 10	4		2	
5, 6, 8, 9, 11, 12	1, 2	3, 7, 10, 13	6		2	
5, 6, 7	1, 2, 3	—	3		3	
5, 6, 7, 8, 9, 10	1, 2, 3	—	6		3	
5, 6, 7, 8, 9, 10, 11, 12, 13	1, 2, 3	—	9		3	

to keep one bulb alight can be used as *our* unit of electrical power. Then the electrical power needed (which equals the number of bulbs alight) is given by the number of units of pressure driving the current multiplied by the number of units of current. Or expressed in single words:

Power = Pressure × Current

This relation holds for the special units used in our experiments. The total amount of the electrical energy changed in this way depends on the number of bulbs alight multiplied by the time during which they were lit. This may be written as:

Energy = Power × Time

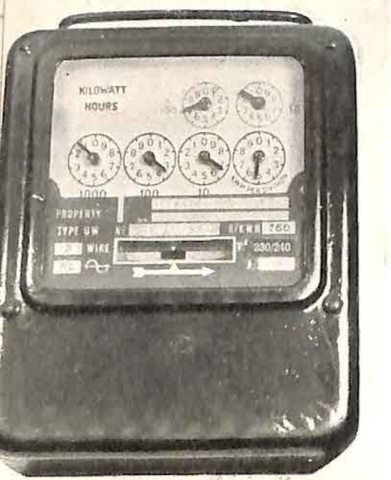
In general practice we use the units already determined, the volt and the ampere, then the unit of power is the product of one volt multiplied by one ampere. This is called a *watt* after James Watt, a Scotsman who invented great improvements in the steam engine. When we use electricity in our homes, the power needed to heat a room is usually more than a thousand watts. So we find it more convenient to use the word *kilowatt* because " kilo " means a thousand. One kilowatt (KW) is therefore a thousand watts. Science is truly international; all over the world in every language people use the units ampere, ohm, volt, and watt, named in honour of famous scientists from four countries. Thus we can write:

Power in watts =
Pressure in volts × Current in amperes

Hence the power consumed is one watt when a pressure of one volt is driving a current of one ampere through a circuit.

The quantity of electrical energy converted into heat when a fire of one kilowatt has been heating a room for one hour is known by scientists as a *kilowatt-hour* (K.W.H.). This is called a *Unit* by the Electricity Board. The number of Units consumed is counted by a meter which is installed in every home and factory. The consumer has to pay for each Unit of electricity he uses as registered by this meter.

FIGURE 41. A domestic electricity meter. Do all the dials read the same way ? What is the reading of this meter ?



The number of Units of electricity consumed by any electrical appliance can be calculated by using the equation we have just discussed. This can be stated as:

$$\textbf{Energy in Units (K.W.H.)} = \frac{\textbf{Power in watts}}{\textbf{1000}} \times \textbf{Time in hours}$$

The cost is obtained by multiplying the number of Units by the charge per Unit. This charge varies considerably according to the use that is made of the electricity and in some places according to the time of the day or night.

You can find the cost of using a 250-watt electric iron for two hours when the charge for one Unit is a penny like this:

$$\text{Cost} = \frac{\textbf{Power in watts}}{\textbf{1000}} \times \textbf{Time in hours} \times \textbf{Charge in pence}$$

$$= \frac{250}{1000} \times 2 \times 1 \text{ pence}$$

$$= \underline{\underline{\tfrac{1}{2} \text{ penny}}}$$

SOME THINGS YOU MAY CARE TO DO

1. Calculate the power needed when the appliances listed in the table on page 40 are used.

2. The table on page 46 gives a list of a few electrical appliances and the power which they take from the mains supply. Examine a few others in your home and add them to the list. Switch off the supply and unplug them so that you can find their power rating. This is usually stamped on a metal label somewhere. Find out the charge per Unit for using these in your home. Complete the table in each column and

calculate the cost of using each appliance for a certain length of time (1 hour, or 6 hours, or a day).

Appliance	Power in watts	Time in use in hours	Charge per Unit in pence	Cost in pence
Iron	250	2	1	0·5
Lamp	100	6	1	0·6
Water heater . .	1000	12	0·5	6·0
Cooker hot-plate HIGH	1800	2	0·75	2·7
Radio	60	8	1	0·48

3. Find out from books in your library more about the lives of Volta, Ampère, Ohm, and Watt. Report on them and their work to the others in your class.

Problem D: WHAT CAN AN ELECTRIC CURRENT DO?

When you look at an electric wire installed in a house, it is not at once certain if this wire is carrying a current. In fact, even if you were very close to it and touched the protective insulation around the wire, you would still be unable to decide if electricity was passing through it. The passage of electricity is only made apparent by the effects it produces.

We have already used one of these effects when we measured the strength of a current by means of a coil and a piece of soft iron. Turn back to page 33. This is the magnetic effect and is observed entirely outside the wire of the coil.

We know an electric current can produce heat and light in some wires, so this is another of the effects. Heat and light are often produced together. The wire in an electric lamp is thinner than that in an electric fire, and is made to glow brighter. In fact, the wire in an electric lamp becomes white hot, whereas that of a fire is only red hot.

Electricity can also be made to pass through a gas when this gas is in a rarefied condition at a very reduced pressure. A glow is then produced in the gas as in the bright red neon tubes. A similar electrical discharge through a gas takes place, producing light without much heat, in the long *fluorescent* tubes that light our homes, shops, factories and streets.

When an electric current passes in one direction through some liquids, sometimes new substances are formed and sometimes others in a pure state are liberated. This is a chemical effect. Modern industry uses the chemical effect to improve its methods of production of many useful materials, such as aluminium, copper, and caustic soda.

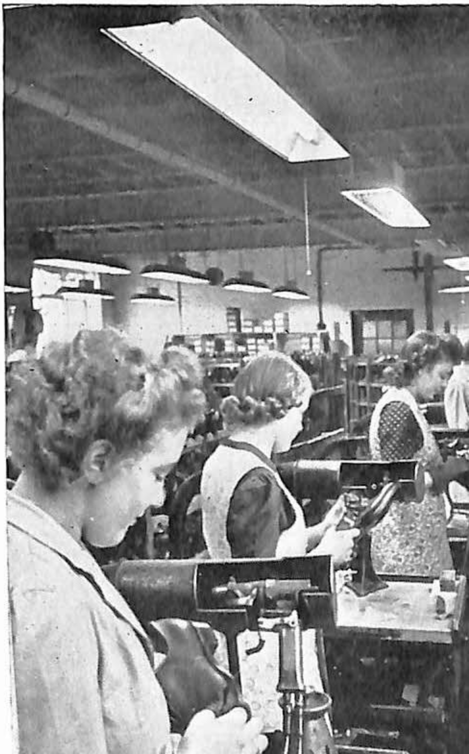


FIGURE 42. Modern fluorescent tube lighting in a factory. This system casts no shadows. Why ?

Courtesy, The British Electrical Development Association

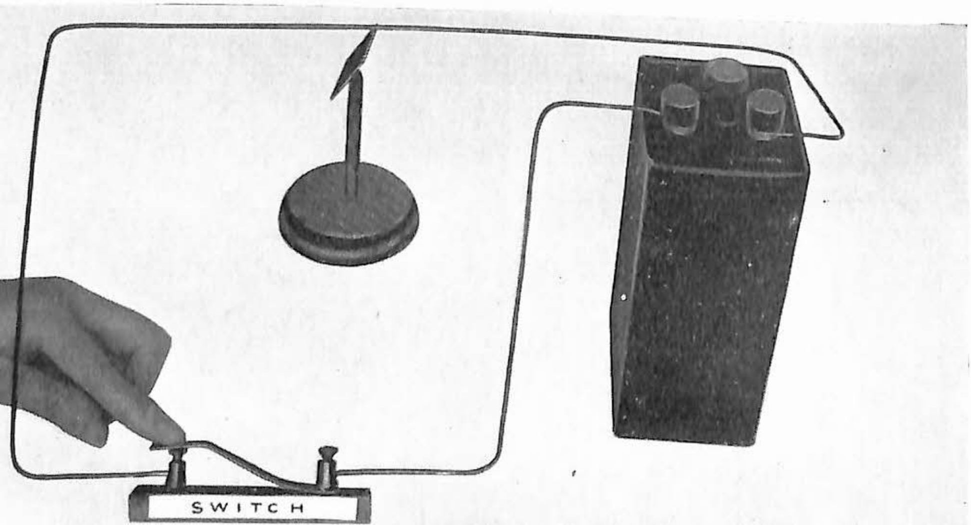
Question 1. **Can an electric current cause some metals to move ?**

In 1819 Hans Christian Oersted, a Danish Professor of Physics, observed that an electric current passing through a wire had a strange effect on a magnet placed near the wire. Let us imitate Oersted's original experiment. It is so simple to perform and well worth doing.

SOME THINGS TO FIND OUT

1. Connect by 1 yard of No. 18 S.W.G. D.C.C. copper wire a 2 volt accumulator to a switch. Straighten part of the wire and pass it directly over and along the needle of a magnetic compass that can swivel freely on a fine upright point. Switch the current on and off. Notice the slight movement of the needle. By switching on and off at the right moments you can increase the swing of the needle as you would increase the swing of a see-saw. The photograph in Figure 43 was taken of a very sensitive magnetic needle at the end of its swing. The needle was in the position of its greatest possible deflection. The movement of the needle must be due to the current passing through the wire. Therefore we conclude that an electric current can disturb a magnet.

FIGURE 43.—What happens when you send an electric current near a magnet that can swivel freely ? Why must the current be switched on for a short time only ?



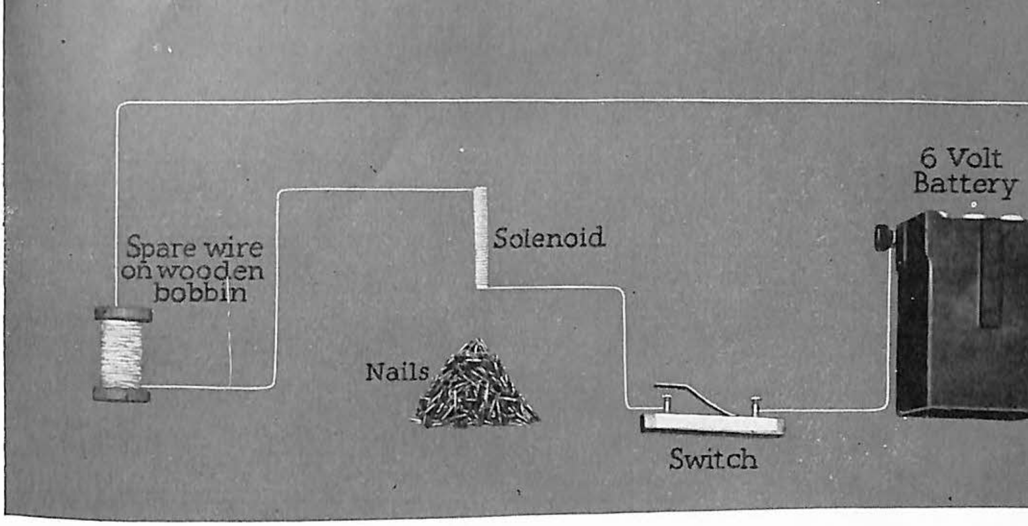


FIGURE 44.—What happens to some of the iron nails when you switch an electric current through a solenoid?

2. What is the effect on iron of a coil of wire of many turns through which electricity is passing? Wind loosely round a pencil two turns of paper to form a tube three inches long. Wind 14 yards from a reel of No. 26 S.W.G. D.C.C. copper wire on a wooden bobbin leaving the end free. Without breaking the wire wind 4 yards more as a single layer round the paper tube and complete the circuit with a switch and a 6 volt motor-cycle battery. Remove the pencil from the paper tube and coil of wire. A coil of this kind is called a *solenoid.* Below and at one end of the solenoid place a heap of thin $\frac{3}{4}$-inch iron nails. Switch the current on, dip the solenoid into the heap of nails, and note how many cling to the solenoid. Catch them on a sheet of paper as you switch the current off. Leave the current flowing for a short time only. Why? The solenoid acts as a magnet in exactly the same way as did the coil in the current-measuring instrument. It may be so very weak that it may not actually lift any of the nails.

Insert into the centre of the paper tube a fat soft iron nail or pack tightly a number of four-inch lengths of

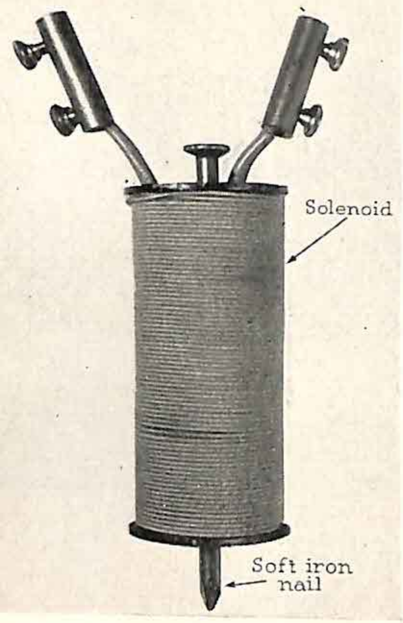


FIGURE 45. Electro-magnet. Many turns of wire wound on a soft iron nail as core.

the soft iron wire used by florists. Repeat the experiment dipping one end of the central soft iron *core* into the nails and observing the number of nails lifted this time.

Wind on the solenoid a second layer from the spare length wound on the wooden bobbin. Repeat the experiment and once more make a note of the number of nails lifted from the heap.

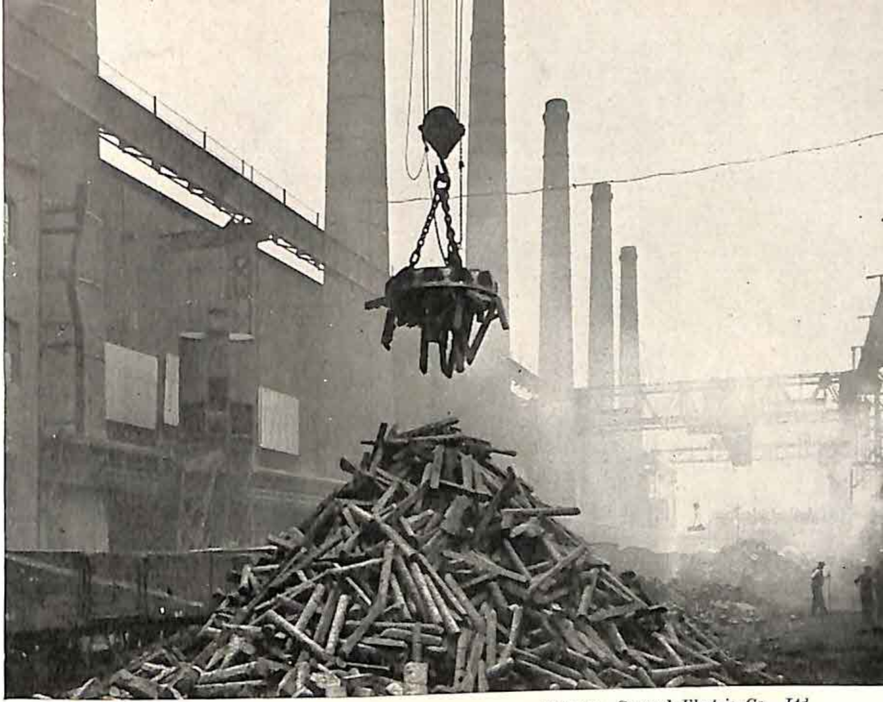
Wind on a third, a fourth, and a fifth layer, and so on until the whole of the spare wire is wound on the solenoid and off the wooden bobbin.

Repeat the experiment in order to observe the number of nails which the solenoid will lift after each layer is completed.

Finally, instead of the one 6-volt motor-cycle battery use two batteries in series. Switch on for a very short time now as the current will be a large one and observe the effect.

Plot a graph of the number of layers of wire against the number of nails lifted.

These experiments show us how to construct an *electro-magnet* which has a strong attraction for soft iron. In Figure 46 one is shown picking up iron bars from a mixture of scrap metals and carrying them on an overhead crane. At a certain position by switching off the current to the electro-magnet these bars are released, drop, and form a heap. Figure 47 shows how a specially designed electro-magnet can be used in a



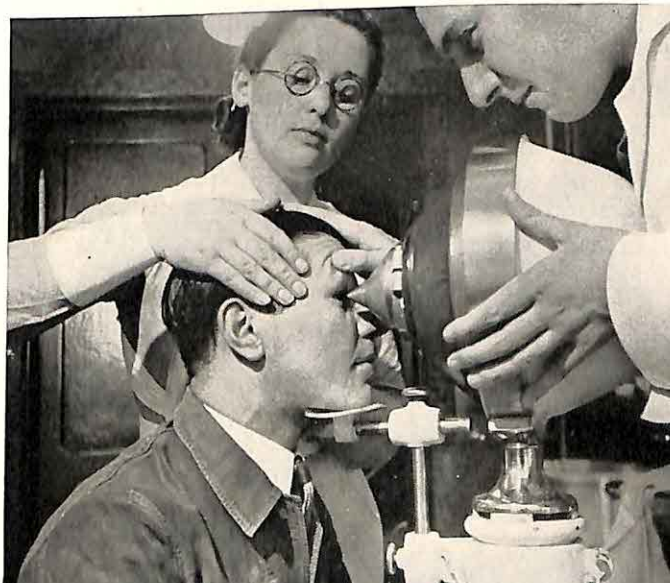
Courtesy, General Electric Co., Ltd.

FIGURE 46. Powerful electro-magnet lifting iron from a mixture of scrap metals.

hospital to remove small chips of iron or steel from the eye of a patient.

FIGURE 47. Electro-magnet removing steel from a patient's eye in a modern hospital.

Weekly Illustrated



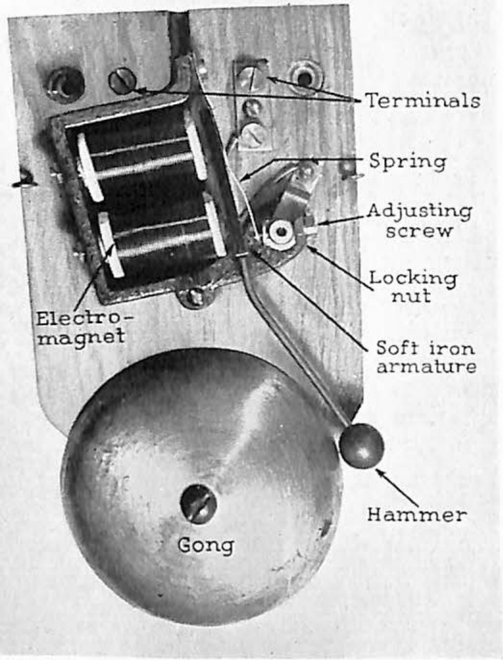


FIGURE 48. Electric bell with its dust cover removed.

SOME THINGS YOU MAY CARE TO DO

1. Examine a morse code buzzer or an electric bell. Take off the protecting case and trace the circuit that an electric current would take from one terminal to the other. Two coils (or in some cases one only) form the electro-magnet. There is a soft iron *armature*, to which a spring is attached, forming the " make and break " with the adjusting screw. Make and break the circuit with your finger. Think how this movement is maintained when a current flows through the bell. Connect the bell to a battery and a switch, and start it ringing. Undo the locking nut, and turn the adjusting screw until the best ring is obtained. Fasten the locking nut. With the electric bell you may have to bend the arm carrying the hammer to get a good bang on the gong. Sketch in your notebook two positions of the bell, one at " make " and the other at " break."

2. Before flashing lamps were used on motor-cars, a small red illuminated arm was raised to indicate the direction in which the car would turn. You can easily make a model of one of these direction-indicators. Refer to Problem C, Question 1. Either use the same coil of wire on a bobbin or prepare another and select a

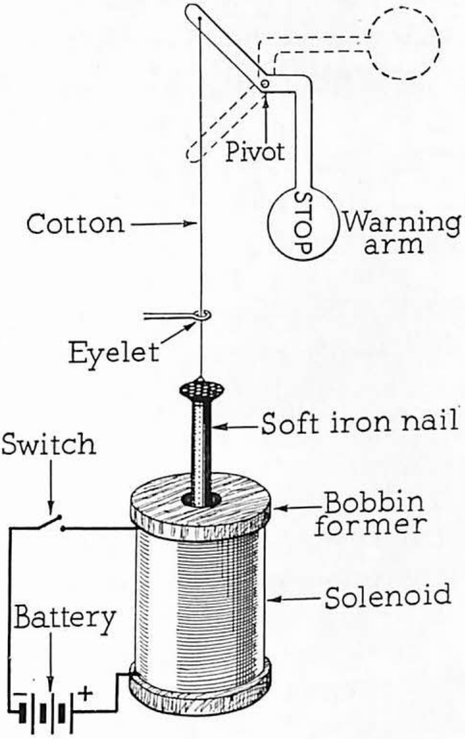


FIGURE 49. Model direction-indicator.

nail to slide freely in its central hole. Suspend the nail by a long piece of cotton passing through an eyelet. The other end of the cotton is fastened to a light double arm which can swing about a smooth pivot. The arm should be so balanced that it is just heavy enough to hang straight down when the current is off. You can add small pieces of wire or small weights to the arm to do the balancing. Connect the solenoid to a switch and a motor-cycle battery of 6 volts.

3. Use books from your library to prepare a story of the life of Professor Hans Christian Oersted, and then make a report to the other members of your class.

Question 2. **How does an electric current produce heat ?**

Electricity encounters a resistance in the whole of an electric circuit. No conductor, however big, offers no resistance at all. Electricity produces heat as it forces its way through a resistor. The more the conductor resists its passage, the greater the heat produced. In some cases the conductor becomes warm, in others hot or even red hot. In a few cases under very special conditions, the conductor becomes white hot. Thick copper wires have small resistances, and thin wires of some *alloys* have large resistances. *Eureka* made of nickel and copper is such an alloy. It is used for making resistors. *Nichrome*, which is made of the metals nickel and chromium, has another advantage—it can resist the current enough to become red hot, and remain red hot without burning away in the air. Hence we use thick copper wires of small resistance to bring an electric current to an electric fire, and then a nichrome wire of big resistance to form the *elements* or bars of the fire.

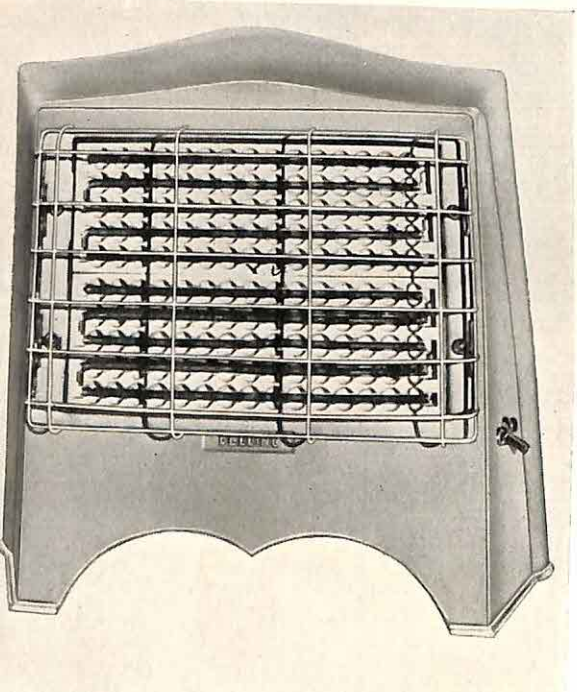


FIGURE 50. Electric bar type fire emitting heat by radiation (60%) and by convection (40%).

Courtesy, Belling & Co., Ltd.

The heat which an electric current produces in any conductor is always exactly equal to the electrical energy which that current supplies. We have used two important equations in the last problem dealing with current and power. These two equations apply to a conductor which is part of a circuit as well as to the whole circuit itself.

One equation is

$$\textbf{Current} = \frac{\textbf{Pressure}}{\textbf{Resistance}}$$

This can also be written as

$$\textbf{Pressure} = \textbf{Current} \times \textbf{Resistance}$$

The other important equation is

$$\textbf{Power} = \textbf{Current} \times \textbf{Pressure}$$

These two equations combined give

$$\textbf{Power} = \textbf{Current} \times \textbf{Current} \times \textbf{Resistance}$$

Thus the heat produced by an electric current in a certain wire depends on the square of the strength of the current and upon the resistance of the wire itself. A current of 1 ampere passing through a conductor produces a certain amount of heat. If three times that current is passed the heat produced will be 3 × 3 or 9 times as great; if 5 times the current is passed, then the heat will be 5 × 5 or 25 times as great. Also, if one conductor has a resistance of 1 ohm and another has a resistance of 2 ohms and the same current is passed through each, the heat produced in the second is always twice that produced in the first.

Let us apply this equation to the case of the electric fire and its connecting cables. Because we wish the main cables to remain cool and the fire to become hot, the wires of the cable must have a small resistance and the wires of the heater bars a large resistance as the same current passes through both.

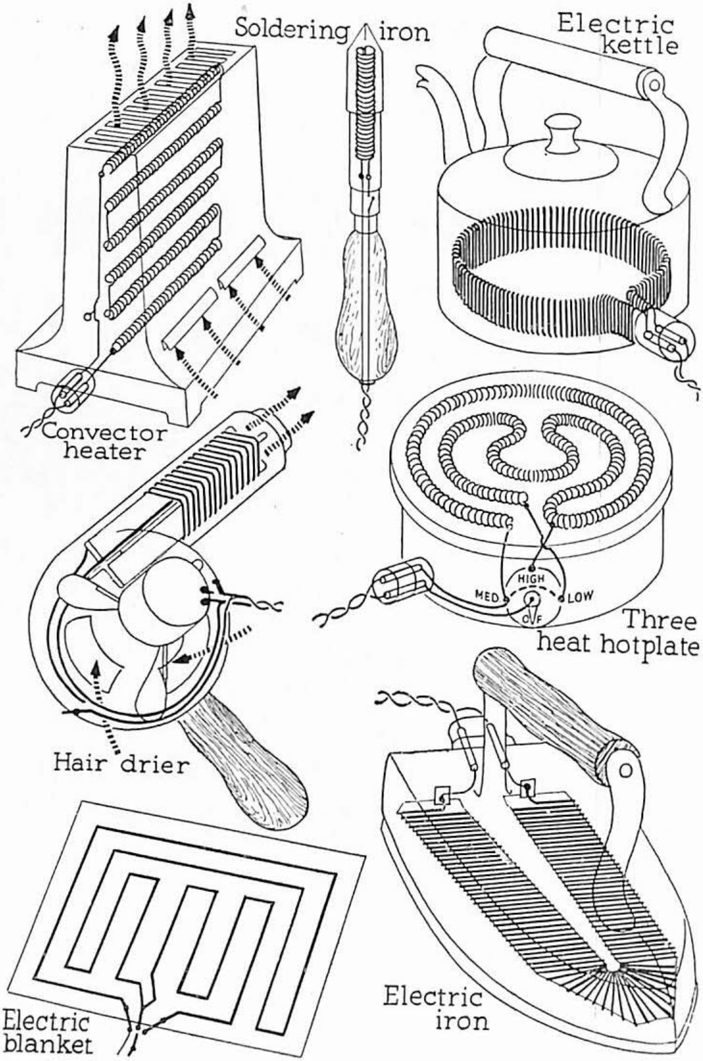


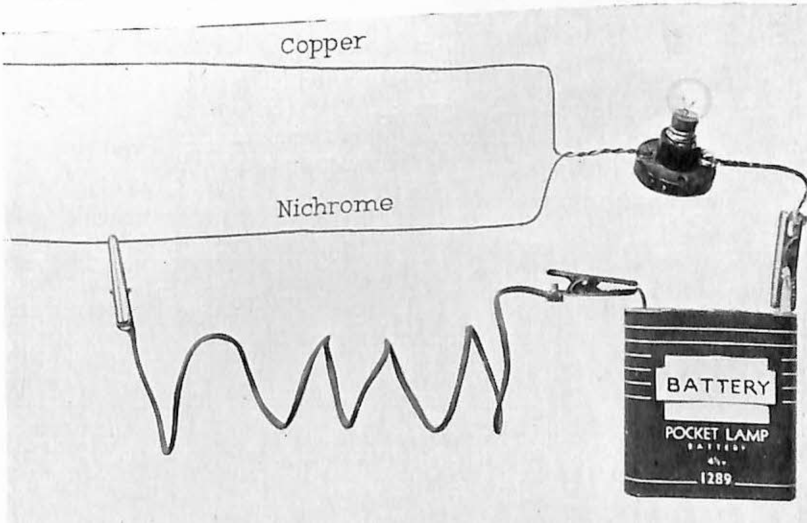
FIGURE 51. Where are the heating elements in each of these appliances? Why are they placed in these positions?

Electric heating elements are used in many different appliances. The convenience of being able to pack an element into a small space makes electricity so easy to use for heating things. In Figure 51 you can see how the nichrome wires of the heating elements are wound on *formers* of mica, firebrick, or porcelain and placed just in the right position to give the heat *where it is* required.

SOME THINGS YOU MAY CARE TO DO

1. Compare the resistance to a current shown by lengths of nichrome and copper wire. Connect a small flash-lamp bulb to one terminal of a flash-lamp battery. To the other terminal connect a wandering lead attached to a crocodile clip as in Figure 52. From one terminal of the bulb fasten two parallel lengths of wire about 2 feet long. One should be of copper No. 30 S.W.G. and the other of nichrome also No. 30 S.W.G. A current lights the bulb as the clip makes contact at various positions on either wire. The bulb will tell you how the nichrome wire resists the current. Does nichrome wire have a bigger resistance than copper wire of the same length and gauge ?

FIGURE 52. Comparing the resistance of copper and nichrome wires.



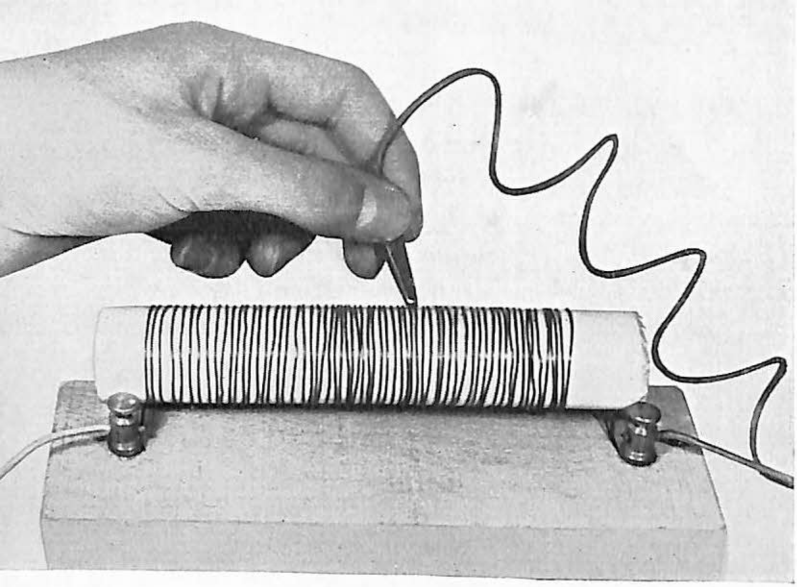
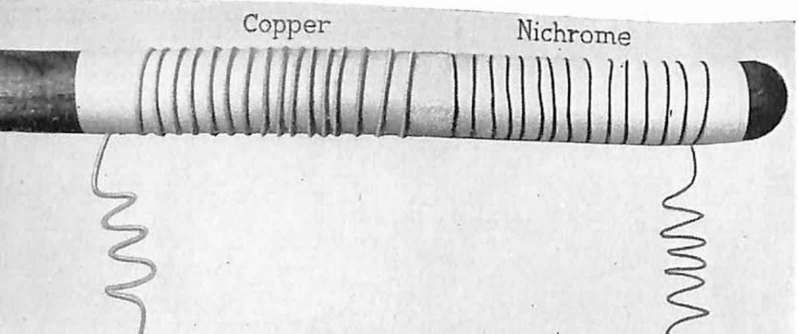


FIGURE 53. A rheostat.

2. How to vary the resistance smoothly. Roll more of the nichrome wire used in the last experiment around a cardboard tube and mount it on a wooden base between two terminals. Rub the clip along the wire on the tube and you will be able to use this as a *rheostat* or a coil which gives you a variable resistance.

3. Compare the heat produced in a length of nichrome wire with that in a similar length of copper wire when the same current flows through both. Connect in series a motor-cycle battery of 6 volts, a switch, and two coils of wire wound on a wooden rod. One coil is made of 60 inches of No. 30 S.W.G. copper wire and the other of the same length and gauge of

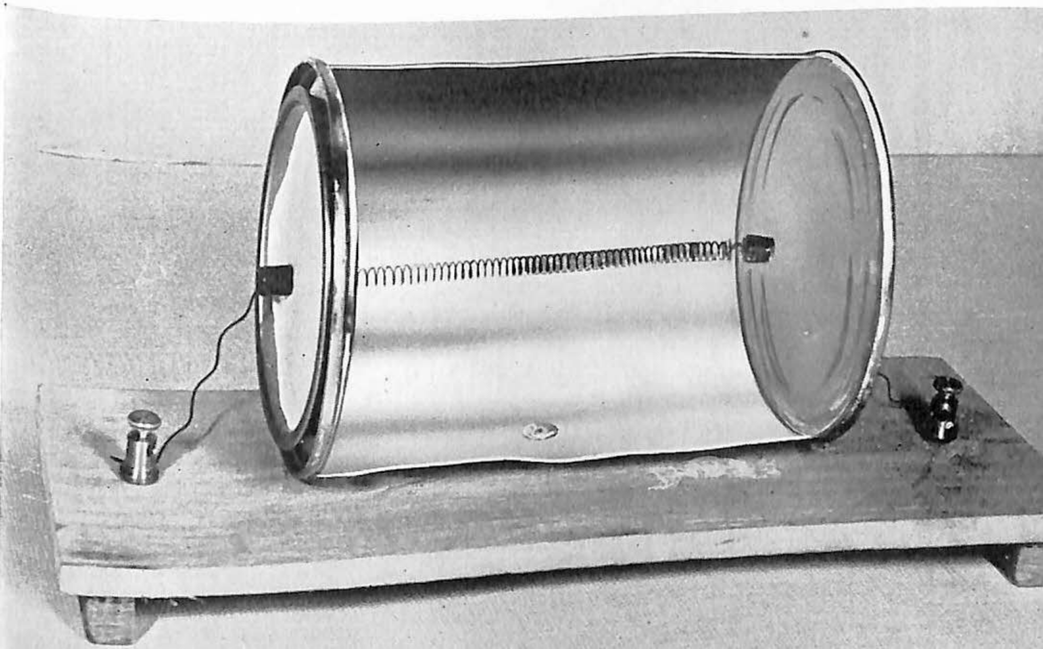
FIGURE 54. Comparing the heat produced in the same circuit by copper and nichrome wires.



nichrome wire. Switch on for about two minutes. Place your hand near both coils in turn to judge the heat produced. Do not leave the current flowing too long because this will spoil the battery. Avoid touching the hot wire.

4. Build a small electric reflector fire. Cut out one half of the side of a tin can which should be about 4″ in diameter and 5½″ long. Knock a hole in both ends and insert firmly in these holes a piece of the stem of a clay pipe. Wind 12″ of No. 24 S.W.G. nichrome wire on a thick knitting needle, withdraw the needle, and mount the ends of the coil of wire in the holes of the two bits of stem. Connect these to two terminals on a wooden base and nail the can to the base also. You will discover that this makes a better radiator of heat if the holes through which you inserted the clay pipe stems are not in the centre of the ends but nearer to the reflector. Why is this? Connect to a 6-volt motor-cycle battery.

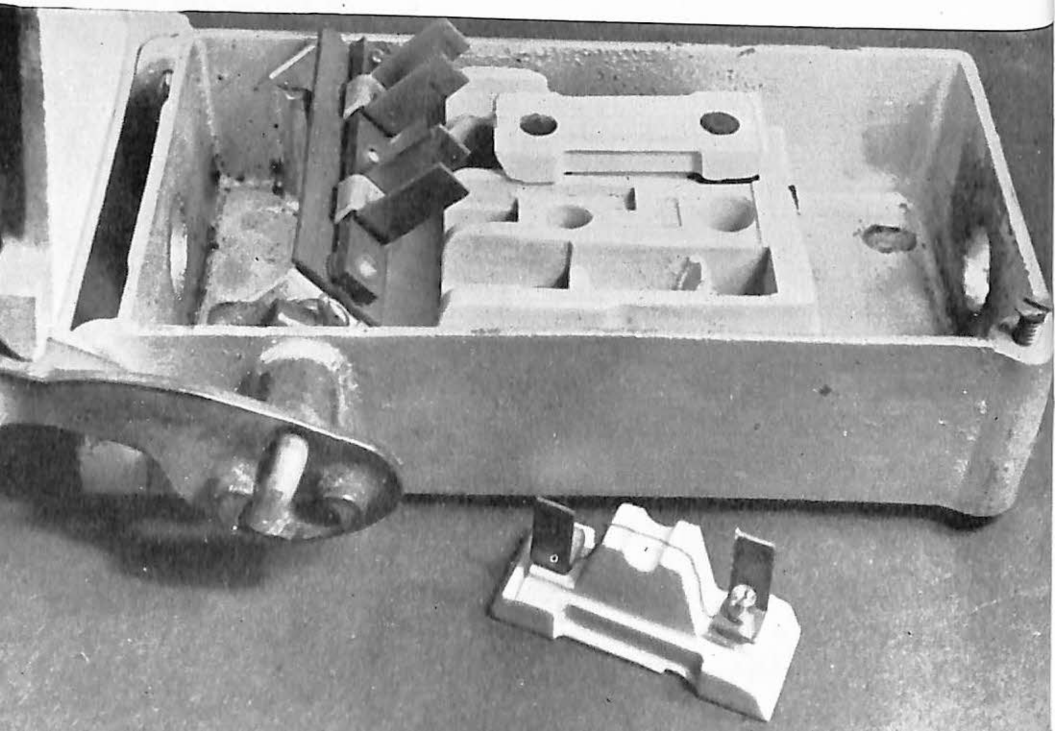
FIGURE 55. Electric reflector fire. Rays of heat are reflected by the shiny interior of the can and these are sent out or radiated forward in a beam.



There is another heating element that is essential in many electric circuits. This is a fuse which is made of a length of fine tinned copper wire. The wire is mounted on a porcelain holder which is easily removed from two spring contacts in a porcelain base. If the current in the circuit becomes greater than a certain value, the heat produced in the fine wire is sufficient to melt it and break the circuit between the contacts. Which has the finer wire: a 5-amp fuse or a 10-amp fuse? Why is this?

Two such fuses are always installed in every parallel circuit in a house wiring system. You will be able to see them in the distribution box of Figure 33. There are also main fuses incorporated in the mains switch box. A fault may occur in the electric wiring circuit in a house. For instance, someone may hammer a nail into a wall just at the place where there are two

FIGURE 56. Mains switch and fuse box. The lid of this box will not open until the handle has been pulled to the "off" position. Why? One fuse has been removed for inspection.



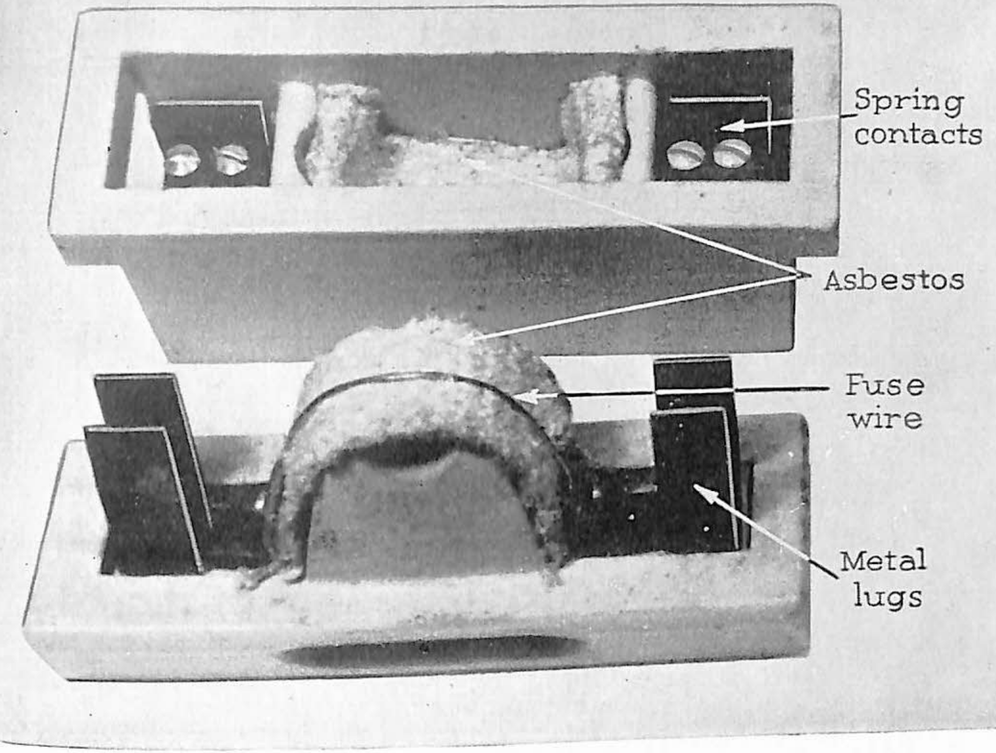


FIGURE 57. Fuse holder and base.

wires connected to the mains supply. The lead to an electric kettle may become loose and break or tear near the entrance to the plug. Thus the two wires may be joined accidentally in this way and form a *short circuit.* The large current passing through this short circuit might cause great heat which could easily start a fire at this point. It is therefore very dangerous indeed to permit such a large current even for a short time. The fuse prevents this from happening because the same current passes through its wire which then heats rapidly, melts, breaks the circuit, and so stops the current flowing. Fuse wire supplied for use in the home is usually graded to melt in the porcelain holder when a current of a certain strength passes through it. We can purchase 5-amp, 10-amp, and 15-amp fuse wire. The correct size of fuse wire must be used in each circuit. Those circuits designed to supply up to 5 amperes only have a 5-amp fuse wire.

Let us calculate the size of fuse wire needed in a circuit which has one electric fire, with two bars of 1000 watts each, connected to a 240-volt mains supply. If the two bars were switched on together the power drawn would be 2000 watts.

Using the equation:

$$\text{Power in watts} = \text{Current in amps} \times \text{Pressure in volts}$$

we get

$$2000 \text{ watts} = \text{Current in amps} \times 240 \text{ volts}$$

or

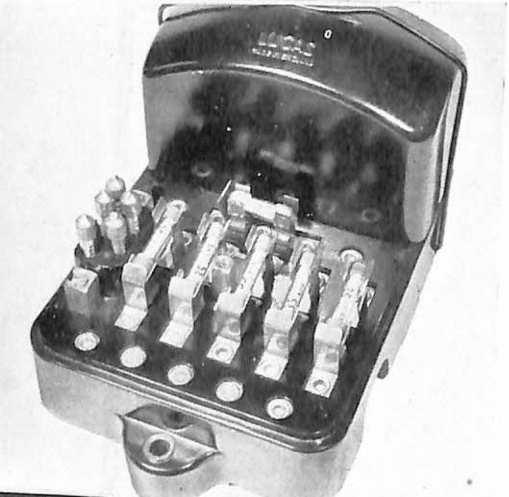
$$\text{Current} = \frac{2000}{240} \text{ amperes}$$

$$= 8{\cdot}3 \text{ amperes}$$

Hence we should use in this circuit a 10-amp fuse wire. This would carry the current when both bars of the fire are switched on but will " blow," that is melt away, if a short circuit occurs.

Motor-cars are also fitted with fuses. Every circuit is protected in the same way as those in a house, although in most cars only one fuse is used. This fuse is inserted in series in the " live " wire near the battery. Frequently the return wire is the framework of the car itself. A motor-car fuse is enclosed in a short

FIGURE 58. Motor-car fuse box with dust-cover removed. Spare fuses are stored on the left.



sealed tube of glass to prevent the spark, produced when the fuse melts and breaks, from setting fire to any petrol fumes about.

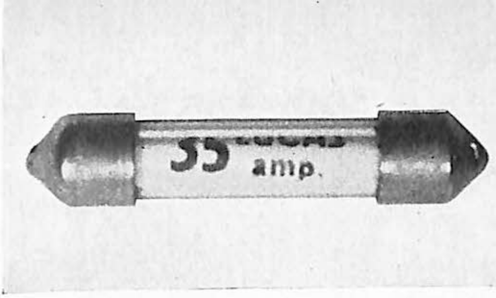
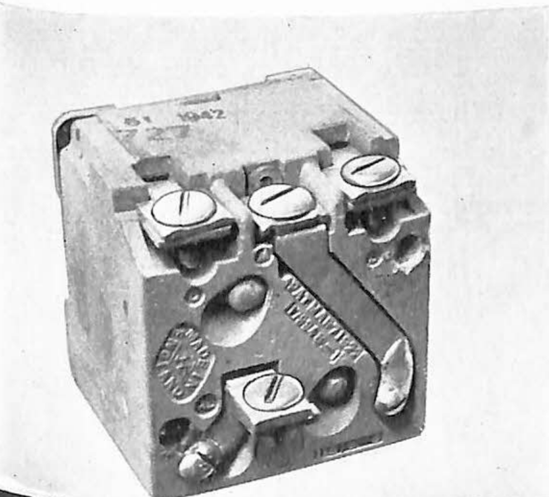


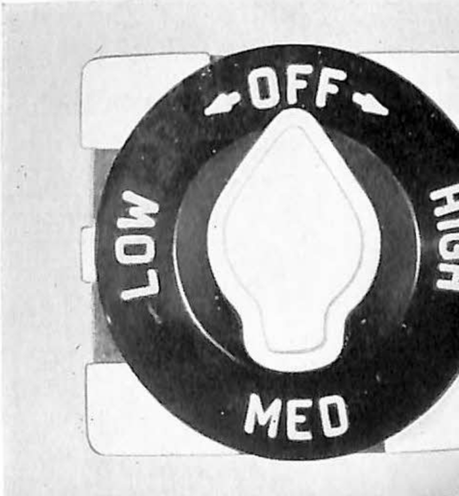
FIGURE 59. Motor-car fuse (35 amp.).

Many hot-plates, blankets, and other heaters have the possibility of three different heats usually marked on the switch as LOW, MEDIUM, HIGH. There is also an OFF position. These heaters are constructed with two equal coils of high resistance wire in series which form the heater elements. The switch is complicated but you can understand how it operates from the four wiring diagrams illustrated in Figure 61.

In the OFF position one terminal, connected to the mains supply, is disconnected entirely from the heater elements and thus no current flows at all. In the LOW position you can trace the current round through both the elements in series. In the MEDIUM position the current passes through one element only. In the HIGH position the current passes through both elements in parallel.

FIGURE 60. Three heat control switch. Front view shows the three positions and "OFF." Back view shows the four terminals. Compare this with Figure 61.





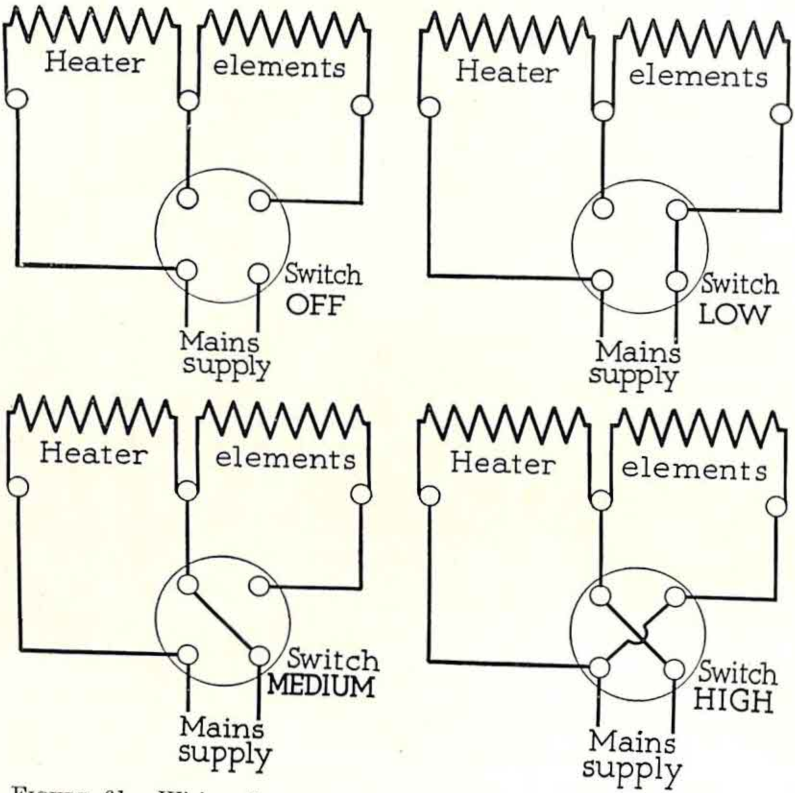


Figure 61. Wiring diagram of a three heat switch controlling a twin wire heater of a cooker hot-plate or blanket.

Using again the equations

$$\text{Power} = \text{Current} \times \text{Pressure}$$

and

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}$$

think how you could change them to obtain the following equation:

$$\textbf{Power} = \frac{\textbf{Pressure} \times \textbf{Pressure}}{\textbf{Resistance}}$$

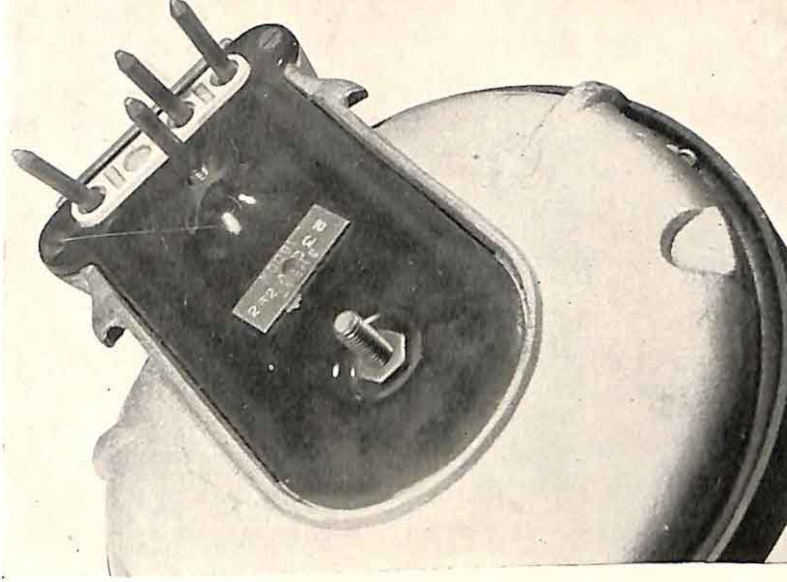


FIGURE 62. A cooker hot-plate. Three pins provide the connections to the two heating elements. Why is there a fourth pin ? The three pins on this hot-plate are set in a porcelain insulating base.

This is now in the correct form for calculating the heat output for the three positions of the switch. Suppose the pressure of the mains supply is 240 volts and the resistance of each coil is 10 ohms.

LOW position. There are 2 resistors of 10 ohms each in series which gives a total of 20 ohms, across which the pressure of 240 volts is sending a current.

Therefore

$$\text{Power} = \frac{240 \times 240}{20} \text{ watts}$$

MEDIUM position. There is 1 resistor of 10 ohms only in the circuit and the same pressure is applied.

Therefore

$$\text{Power} = \frac{240 \times 240}{10} \text{ watts}$$

HIGH position. The current passes in two directions and each way the resistance is 10 ohms. Thus there are two powers to add together.

Therefore

$$\text{Power} = \frac{240 \times 240}{10} + \frac{240 \times 240}{10} \text{ watts}$$

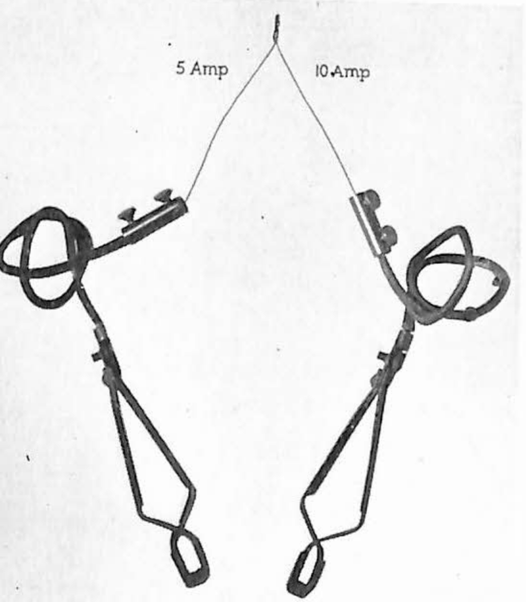
$$= \frac{240 \times 240}{5} \text{ watts}$$

The heat output in each case is supplied by the power we have just calculated. We need not work these equations out any further, as we can see from them that the heat output at MEDIUM, is twice that at LOW, and the heat output at HIGH is twice that at MEDIUM. In other words, the LOW, MEDIUM, and HIGH heat outputs are in the ratio of 1, 2, and 4.

SOME THINGS YOU MAY CARE TO DO

1. Connect with thick copper wire a 6-volt motor-cycle battery in series with 3 inches of 5-amp. fuse wire, 3 inches of 10-amp fuse wire, and two strong clips. You can switch on the current by placing the clips over the terminals of the battery. Note how quickly the 5-amp fuse wire "blows" whilst the 10-amp fuse wire remains intact.

FIGURE 63. Testing fuse wire.



2. Examine the fuses in the distribution board in your home. Turn off the main supply switch

first. Compare the sizes of the fuse wires with those on a spare fuse wire card. Note the current —5, 10, or 15 amperes—that each parallel circuit can carry before the fuse "blows." Compare this current with the current supplied to all the appliances when all are switched on at the same time. Lighting circuits usually have 5-amp fuses and heating circuits 10- or 15-amp fuses. Do you find this is correct in your home ?

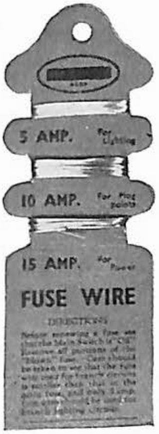


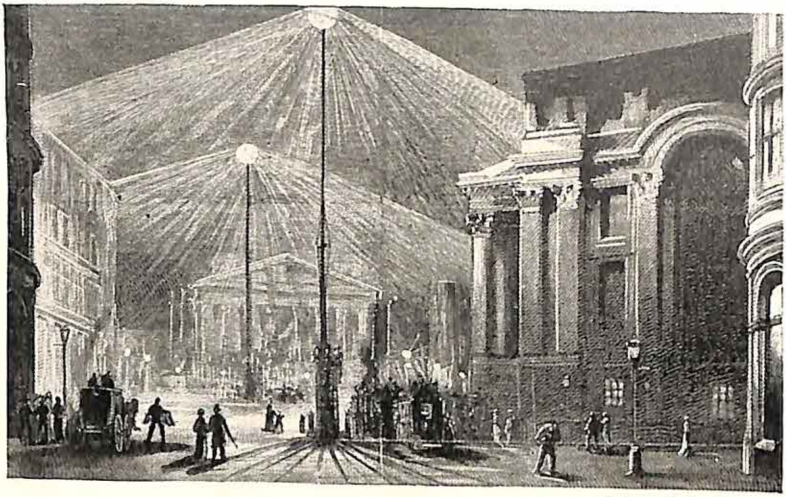
FIGURE 64. Fuse wire.

Problem D: What can an electric current do ?

Question 3. **How does an electric current produce light ?**

What are the very special conditions under which a conductor will become white hot and thus give out light ? Firstly, the conductor must remain rigid and not melt when it reaches the high temperature of white heat. Secondly, it must not burn away with the oxygen of the air.

A modern electric light lamp has a very fine tungsten wire filament of high resistance. This filament becomes white hot without melting when a current flows through it and thus gives out a bright light. The filament does not burn away because the lamp has no oxygen left in it. Usually there is an *inert* gas in the lamp, that is, a gas which does not combine with the filament in any way.



Picture Post Library

FIGURE 65. Arc lamps in use, 1881, Mansion House, London.

The first electric light was not made in this way. It was made by passing an electric current between two rods of carbon to form an electric arc. The arc burnt with a piercing blue flame, which was much too strong and dangerous to be used in the home. But this light delighted the people of those days and was used in streets, factories, theatres, and lighthouses. The electric arc is still used today for *welding* metals together, and for heating substances to a high temperature in very hot electric furnaces. The days of electric arcs quickly passed when the first glass electric lamps were made in glass bulbs.

FIGURE 66. Arc welder at work.

Fox Photos, Ltd.

A study of how the modern electric lamp has been developed, stage by

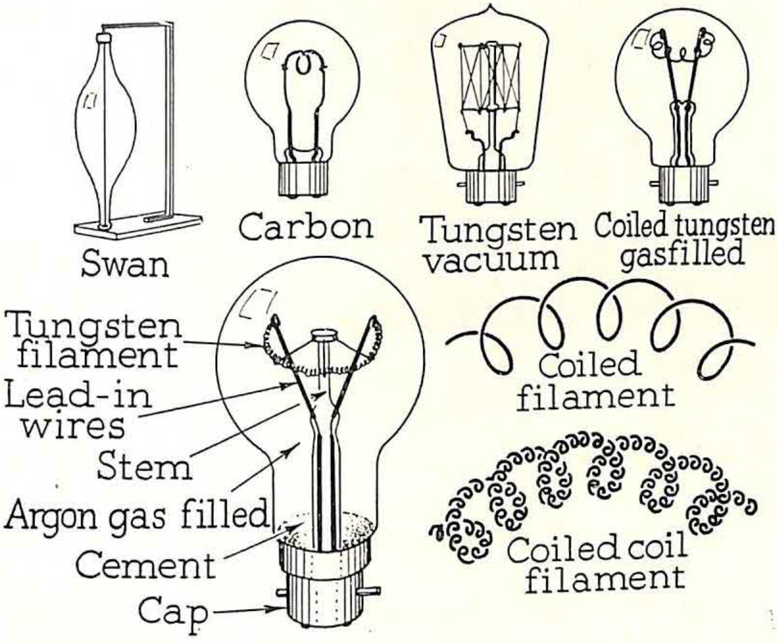


FIGURE 67. The development of the electric lamp.

stage, from the original design of 1880 by Edison in America and Swan in England, shows clearly how scientists work. They experimented at each stage to eliminate faults and to increase the amount of light emitted for every watt of electrical power consumed. Figures 67 and 69 show the results of their labours as the years passed by. Each lamp represents a new stage in design incorporating a new discovery of the scientists. The coiled coil filament of the latest type of lamp is made of a hard silvery white metal called *tungsten* and the lamp itself is filled with a mixture of *argon* and *nitrogen*—two inert gases. These lamps are robust and lasting, but only about one-tenth of the electrical power used by the lamp is emitted as light, the remainder being lost as heat.

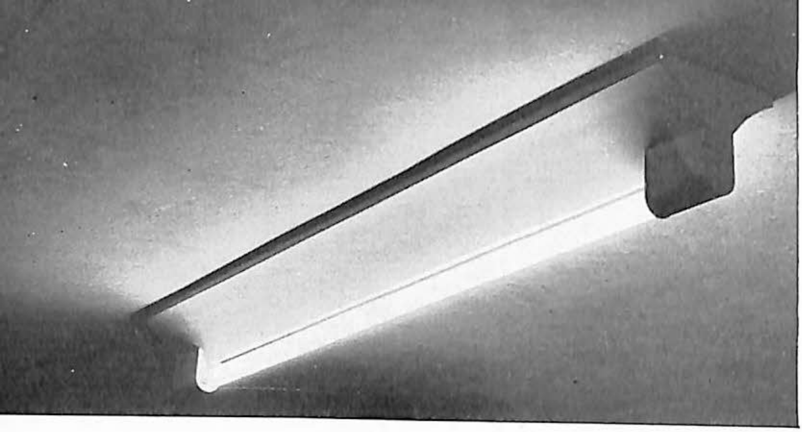


FIGURE 68. Fluorescent tube lighting. This type is mounted on the ceiling. It has a "Seagull" pattern reflector. Why has the reflector this name ?

Another era in electric lighting has appeared. The long brightly lit fluorescent tube converts much more of the electrical energy into light. In fact, we are getting nearer to producing light without heat.

The table which follows shows how success has been achieved during the past 100 years in man's struggle to turn darkness into daylight.

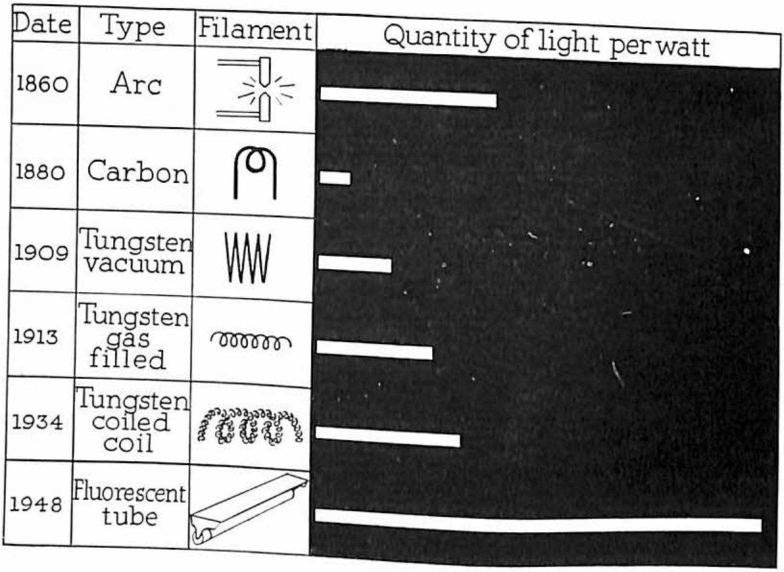


FIGURE 69.

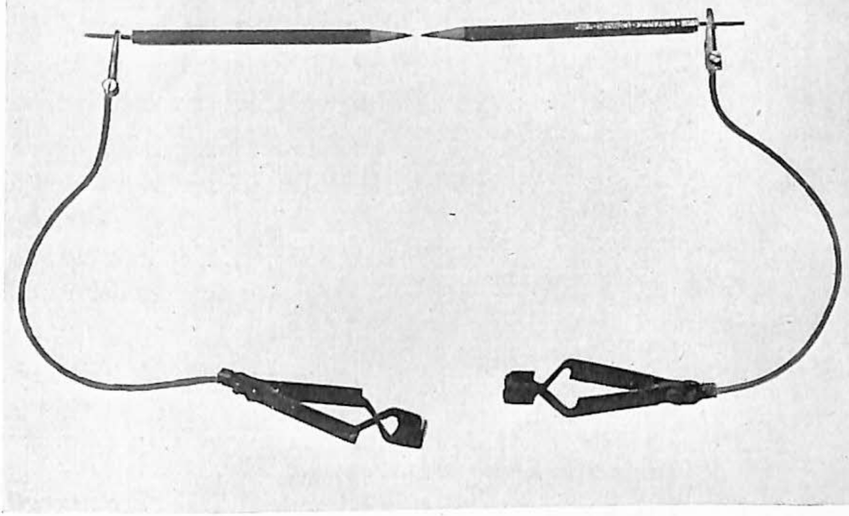


FIGURE 70. How to prepare two " lead " pencils to form an electric arc.

SOME THINGS YOU MAY CARE TO DO

1. Sharpen two " lead " pencils to fine points. Cut off about half an inch of the wood at the other ends. Connect the projecting pieces of " lead " by crocodile clips, thick flexible copper wire, and strong clips, to four 6-volt motor-cycle batteries in series. Now bring the two points of the pencils together and then separate them slightly. Between the two points an arc will " strike " across the " leads." Why should all electrical connections be tight or, better still, soldered ? After the arc has been burning for a short time, allow it to cool and then examine carefully the points. Are they the same shape now ? Which was connected to the positive and which to the negative terminal of the batteries ?

2. Obtain an old electric lamp. Examine every part of its construction and make a sketch in your notebook. How are the wires sealed in through the

glass ? How is the gas sealed in the lamp ? How are the terminals set relative to the pins on the side of the lamp ? Very carefully break it in a cloth to prevent the glass from flying about.

3. Examine an electric lamp holder of the type called a bayonet holder. Take this to pieces. Make a sketch of it in your notebook. How is a firm contact made with the terminals on the base of the lamp ?

4. Set up side by side three electric lamps of different powers, say 15, 75, and 150 watts. Switch one on at a time and try to estimate the amount of light which it emits. Compare your estimate with the power in watts marked on the lamp.

5. Make a collection for your school of electric lamps of different types. Label each type with all you can find out about it.

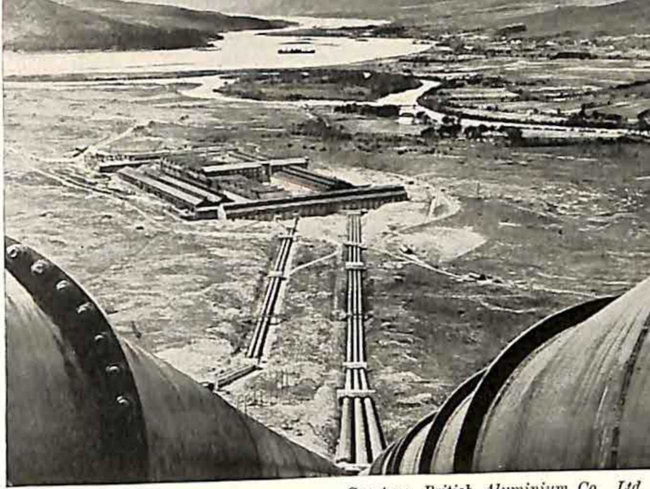
6. Break open a coiled coil filament lamp and examine with a magnifying glass the coiled coil filament. Make a sketch in your notebook of part of the filament.

Problem D: What can an electric current do ?

Question 4. **What chemical changes may take place in an electric circuit ?**

An electric current can produce a chemical change in certain parts of a circuit, but we do not often meet this in our homes. There are plenty of applications in industry. The industrial products of such processes are familiar to us, although many of us do not realize this. Try to find the letters EPNS on the back of some cutlery. What do these letters mean ? How does a motor-car radiator get such an even protective coating of chromium ?

Most of the copper and aluminium we use today is prepared and purified by an electric current producing



Courtesy, British Aluminium Co., Ltd.

FIGURE 71. Hydro-electric aluminium factory at Lochaber, Scotland.

a chemical change in a circuit. Enormous electric currents are required to produce aluminium cheaply and in reasonable quantities. This is why big aluminium factories are set up where there is an abundant supply of water power to produce cheap electricity.

SOMETHING TO FIND OUT

Arrange in a series circuit a flash-lamp battery, a miniature bulb, a switch, and two carbon rods. Put the two carbon rods in a glass tank and allow them to touch one another. Switch on the current. The bulb lights. Make solutions of various substances and test them, one at a time, between the two carbon rods in the glass tank. Try some salt, lemon juice, vinegar, a drop of sulphuric acid, sugar, copper sulphate, and anything else you wish. What happens if you put distilled water only in the tank? As you try each

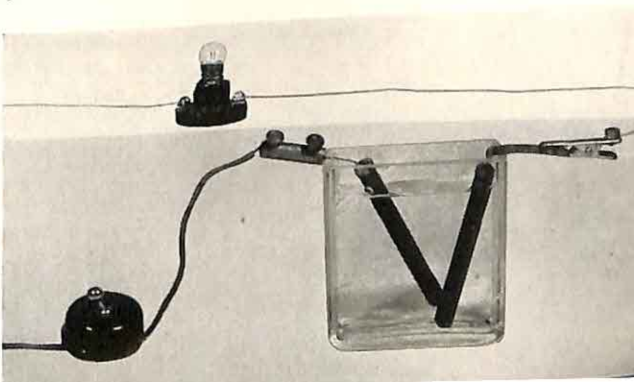


FIGURE 72. Will electricity flow through liquids?

solution, change the direction of the flow of the electric current. Some of the solutions will permit current to flow to light the bulb. Some will allow the current to pass easily, some with more difficulty, and others not at all. Make a list of those solutions that do allow the current to flow and note anything you see happening on or near the carbon rods.

You may find out any of these facts:

1. the current flow increases as the rods come together;
2. the current flow increases as the solution is made stronger;
3. bubbles of a gas form on the rods;
4. red clean copper deposits on one of the rods, and the longer the time the current flows the thicker the deposit;
5. the direction of the flow of the current determines the rod on which the copper is deposited;
6. the colour of the solution changes.

Certainly there is some chemical change taking place in some of these cases. Look at the named labels attached to Figure 73. A solution through which electricity passes is called an *electrolyte*. Chemical changes are only seen on or near the *electrodes*. The electrodes are of two kinds: the *anodes* connected to the positive plate, and the *cathodes* connected to the negative plate of a battery. The whole process is called *electrolysis*. We have already said that an electric current flows from the positive to the negative plate of a battery. Thus the direction of flow

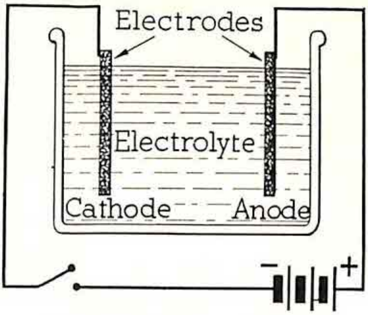
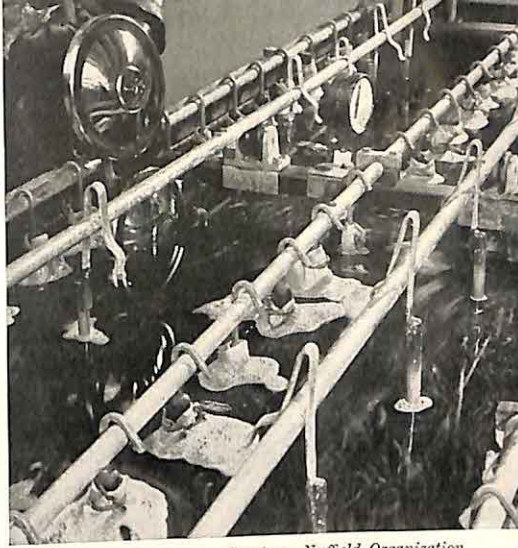


FIGURE 73. Electrolysis.



Courtesy, Nuffield Organization

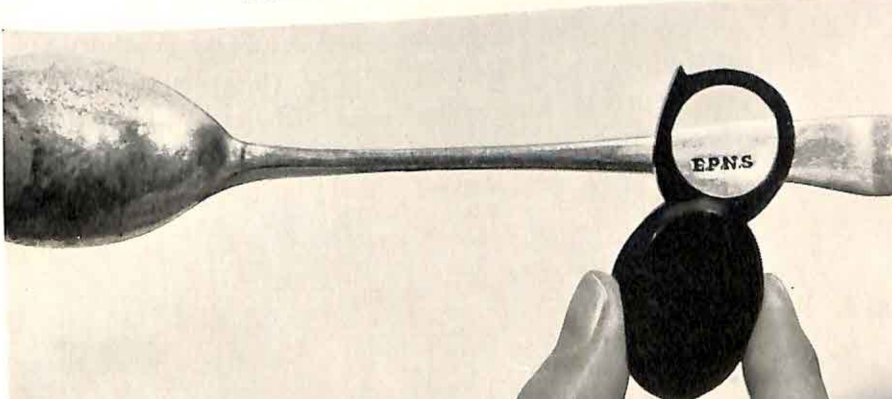
FIGURE 74. Electro-plating in a factory: motor-car wheel hubs getting their first coating of nickel as a base for a chromium finish.

of the electric current in the electrolyte is from the anode to the cathode. When one metal is deposited on another, such as copper on the cathode, the process is called electro-plating and is purposely done for various reasons. It may make it more attractive (silver on nickel), or prevent it rusting (nickel on iron), or make it harder (chromium on nickel), or even make it bigger as when metals are plated on the worn bearings of some machines.

Iron rusts but tin, nickel, and chromium do not. We plate steel bumpers of motor-cars to prevent rust and to make them look clean and bright. A thick layer of nickel is first deposited, then over this a thin layer of chromium is plated.

Spoons and forks of solid silver are bright and pleasant to look at, but weak to use and costly to buy. Hence we make a strong spoon and fork of nickel alloy, and then *E*lectro *P*late the *N*ickel with *S*ilver. Now you know why they are stamped E P N S to distinguish them from solid silver ones.

FIGURE 75. E P N S mark on a spoon.



1. Soak a piece of blotting paper in a solution of potassium iodide and starch. Lay this on a sheet of tin plate. Connect the negative terminal of an accumulator or motor-cycle battery to one corner of the plate, and the positive terminal to a length of stiff copper wire. You can draw designs on the blotting paper with the copper wire if it is bent in the form of a "nib." Electrolysis takes place and liberates iodine from the potassium iodide to give the starch a blue colour. At which electrode does the iodine appear? Can you think of a way of doing a similar experiment to tell you which are the positive and negative plates of a battery?

2. Fasten two platinum electrodes (if your teacher can get these for you) to two bent copper wires. Insulate the wires and the join with some melted wax.

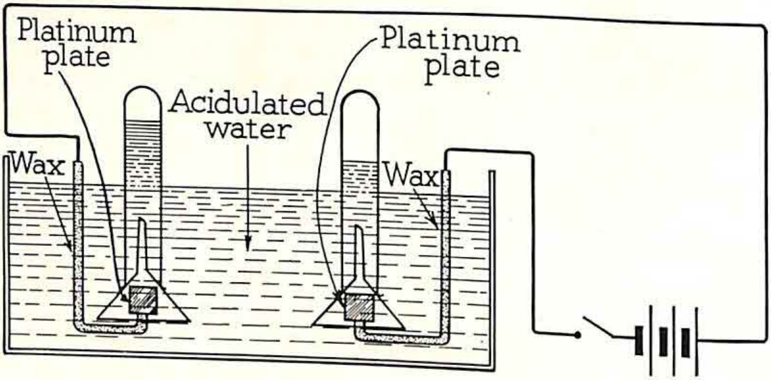


FIGURE 76. Electrolysis of acidulated water.

Immerse them in a large wide tank. Add water with a few drops of sulphuric acid. Over each electrode put a funnel and a test-tube as in Figure 76. Switch on the current and collect the gases formed. What do you think the gases are? How can you test this to see if you are correct?

3. By electrolysis Sir Humphry Davy discovered two new elements: potassium (K) and sodium (Na). Although England and France were at war at this time, Napoleon gave him a prize for his discovery. Can you find out from books in your library more about his discovery and tell your class?

NOTES ON THE UNIT

The three equations which you will find most useful in calculations about electric currents and appliances are:—

$$\text{Current } (\textit{amperes}) = \frac{\text{Pressure } (\textit{volts})}{\text{Resistance } (\textit{ohms})}$$

$$\text{Power } (\textit{watts}) = \text{Current } (\textit{amperes}) \times \text{Pressure } (\textit{volts})$$

$$\text{Energy } (\textit{Units}) = \text{Power } (\textit{kilowatts}) \times \text{Time } (\textit{hours})$$

Some useful facts:

Pressure of—

a dry cell = 1·5 volts direct
an accumulator = 2·0 volts direct
a cycle dynamo = 6·0 volts alternating
a car battery = 6·0 or 12·0 volts direct
a mains supply in the British Isles = 240 volts alternating

British Railways Southern Electric railway system = 660 volts direct

Current taken by—

a flash-lamp bulb = 0·15 or 0·3 amperes
a cycle headlamp bulb = 0·5 amperes
a cycle tail-lamp bulb = 0·04 amperes
a car sidelamp bulb = 0·5 amperes
an arc welder = 50 to 150 amperes
a self-starter of a motor-car = 40 to 50 amperes

Power needed by—

a car sidelamp bulb = 3 or 6 watts
a toaster = 450 to 1000 watts
a water immersion heater = 750 to 1000 watts
one bar of a fire = 1000 watts
a cooker hot-plate at max. = 1800 watts
1 Unit = 1 kilowatt-hour = 1000 watt-hours

1. Is it possible to make a simple cell by putting the zinc and the copper plates in separate tanks of dilute acid ?

2. Draw a sketch showing how an electric torch works.

3. Why should the cap or lid of a torch be kept clean and free from dust ?

4. When is a torch battery " run down " ?

5. Why should we throw away a torch battery as soon as it is " run down " ?

6. Why does an electrician carefully clean the ends of wires before he connects them to plugs and sockets ?

7. Why does a switch have a strong spring inside it to break the circuit suddenly ?

8. Explain why it does not matter in which order you put the various parts of a circuit, such as switch, battery, and bulb ?

9. Why does one faulty bulb in a circuit of " fairy lights " put out every light ?

10. How can you find the faulty bulb in a string of " fairy lights " which do not light ?

11. Design the wiring diagram for a bedside switch to turn out the room light.

12. Why should bathroom switches be mounted on the ceiling and worked with a cord ?

13. Why are there three pins on electric plugs ?

14. Why do some sockets automatically close two holes when the plug is withdrawn ?

15. Why are house electric wires laid in metal tubes or in lead cables ?

16. On damp days why do you sometimes hear and see electricity jumping across the insulators on pylons ?

17. Why are telephone wires laid underground when they cross beneath electric power lines ?

18. Why are the handles of an electrician's pliers and a fireman's axe covered with rubber ?

19. When a fuse " blows " in an electric circuit why must we always look first for the cause of the short circuit ?

20. Why must we be careful to replace a " blown fuse " by wire which will just carry the correct maximum current ?

21. What are the usual causes of a " blown " fuse in a house circuit ?

22. We often see birds sitting on power wires carrying electricity to houses. Why are they not electrocuted ?

23. Examine a 15-watt and a 100-watt electric lamp. Which has the longer and which the thicker filament ?

24. Why would you be electrocuted if you touched the conductors carrying electricity in your house, and not if you touched those in a flash-lamp ?

25. Read the dials of the electric meter in your house every day at the same hour, and make a graph of the consumption of electricity against time.

26. Examine your last electricity bill. How is it calculated ?

27. When electricity is used to heat a fire or light a lamp, does it matter in which direction the current flows ?

28. Why must pans for use on an electric hot-plate have their bases absolutely flat ?

29. The elements of a " radiant " type of boiling ring are bent to form two loops or circles. Sketch these three times and colour your sketches to show how they are heated when the switch is in each of its three positions : low, medium, and high.

30. Make three sketches to show how you would be warmed in a room when you sit at one end and opposite to you there is (*a*) a reflector fire (radiation), (*b*) a bar type fire (radiation and convection), or (*c*) a convector heater (convection).

EXAMPLES TO WORK OUT

1. What is the resistance of a lamp if it takes a current of $\frac{1}{2}$ ampere at a pressure of 240 volts ?

2. What pressure is needed to send a current of 1·5 amperes through a circuit whose resistance is 8 ohms ?

3. What current flows when a pressure of 2 volts is maintained across a resistor of 12 ohms ?

4. What pressure is needed to send a current of 1 ampere through a resistor of 40 ohms ?

5. An ammeter reads 5 amperes when it is placed in series with an electric fire connected to a mains supply of 240 volts. What is the resistance of the electric fire ?

6. A dry cell of pressure 1·5 volts sends a current of 0·1 amperes through a resistor of 10 ohms. What is the resistance of the cell ?

7. Resistors of 6 and 2 ohms are arranged in series with a battery whose resistance is 7 ohms. A current of 0·2 amperes flows round the circuit. Draw the wiring diagram of the circuit. Calculate

(*a*) the pressure across each resistor,
(*b*) the pressure across the battery,
(*c*) the E.M.F. of the battery.

8. A searchlight requires a current of 100 amperes delivered at a pressure of 60 volts. What value of resistor connected in series with the searchlight would be needed so that it could be used with the 240 volts mains supply ?

9. A torch has three unit cells each giving a pressure of 1·5 volts. What is the pressure of the battery in volts ?

The bulb is marked 3·5 volts 0·3 amps. What is the power needed to light it ?

When the torch is switched on, how much pressure is lost driving the current through the cells themselves ?

If the cells burn for 20 hours continuously, how many watt-hours of energy do they generate together ?

10. Using the useful facts in the notes on page 77, calculate

(*a*) the total current supplied to the head and tail bulbs of a cycle,
(*b*) the total power needed to light these bulbs,
(*c*) the total energy converted by the bulbs into light and heat if you cycle for 3 hours with your dynamo generating electricity.

11. If a motor-car self-starter has to be used for five seconds to start the engine, how long must the engine run to give to the battery the same amount of electrical energy as was consumed in starting ? The battery has a pressure of 12 volts, the self-starter draws a current of 40 amperes, and the engine charges at 8 amperes.

Because of the wastage at charging and discharging, an accumulator requires four units of electrical energy put into it for every unit it gives out. How long must the engine run to recharge the battery to its original condition ?

12. In a large shop there are 100 lamps of 150 watts, 20 lamps of 100 watts, 200 lamps of 60 watts, and 25 lamps of 40 watts. These are all switched on for ten hours a day during the winter months. If electricity costs one penny a Unit, how much does it cost every day to light this shop ?

SCIENCE ON THE MARCH

The Air and You
Water and Life
The Weather and the Earth
Life and Food
Health
Energy and Engines
Hearing and Seeing
Electric Currents
Magnets and Electric Power
Earth and Universe
Heating and Cooling
Birth and Growth
Metals and Man

LONGMANS